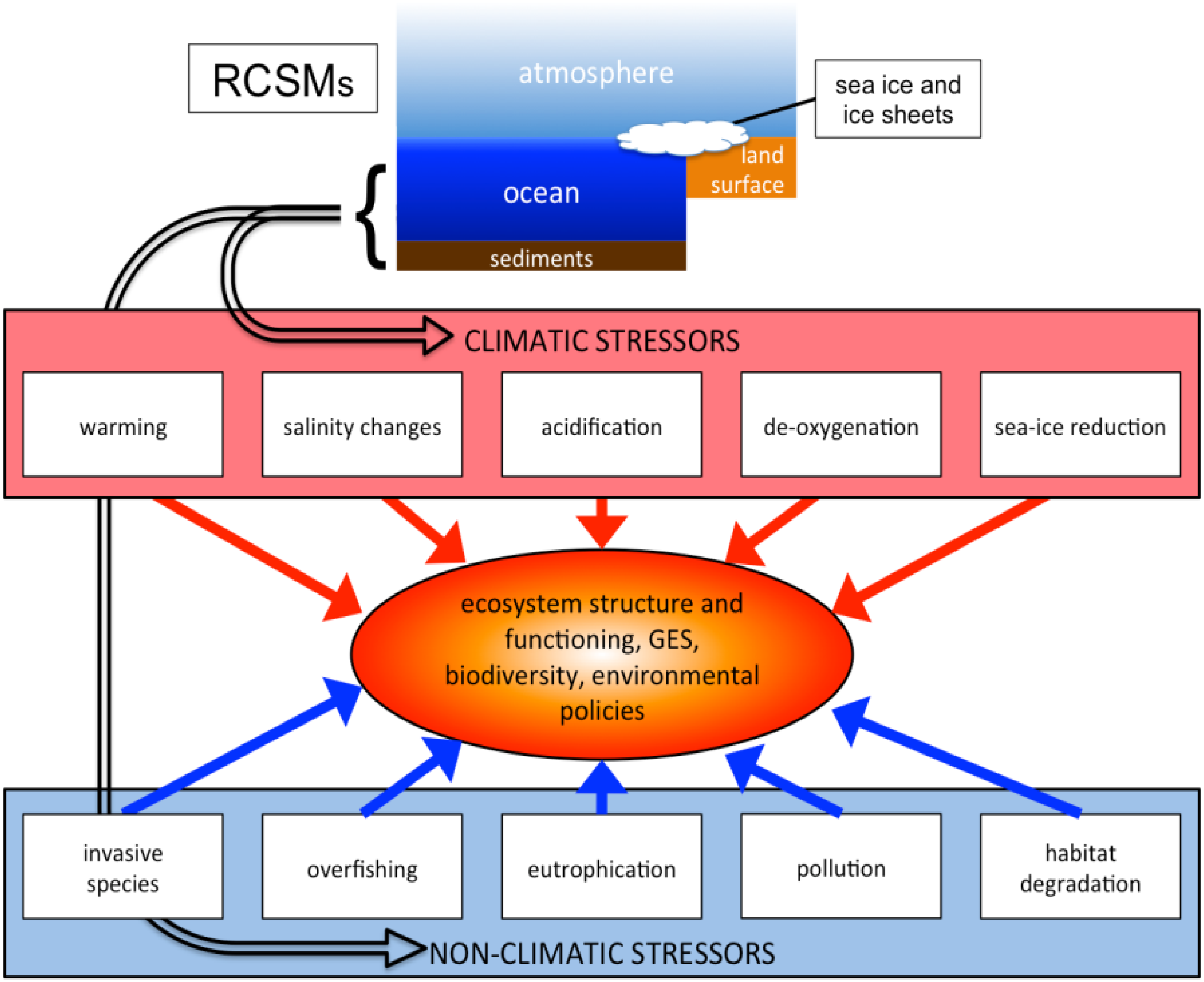
Climate of the Baltic Sea Region

Regional climate system modeling - reconstruction of past climate and future projections

Prof. Dr. Markus Meier
Leibniz Institute for Baltic Sea Research Warnemünde (IOW)
markus.meier@io-warnemuende.de

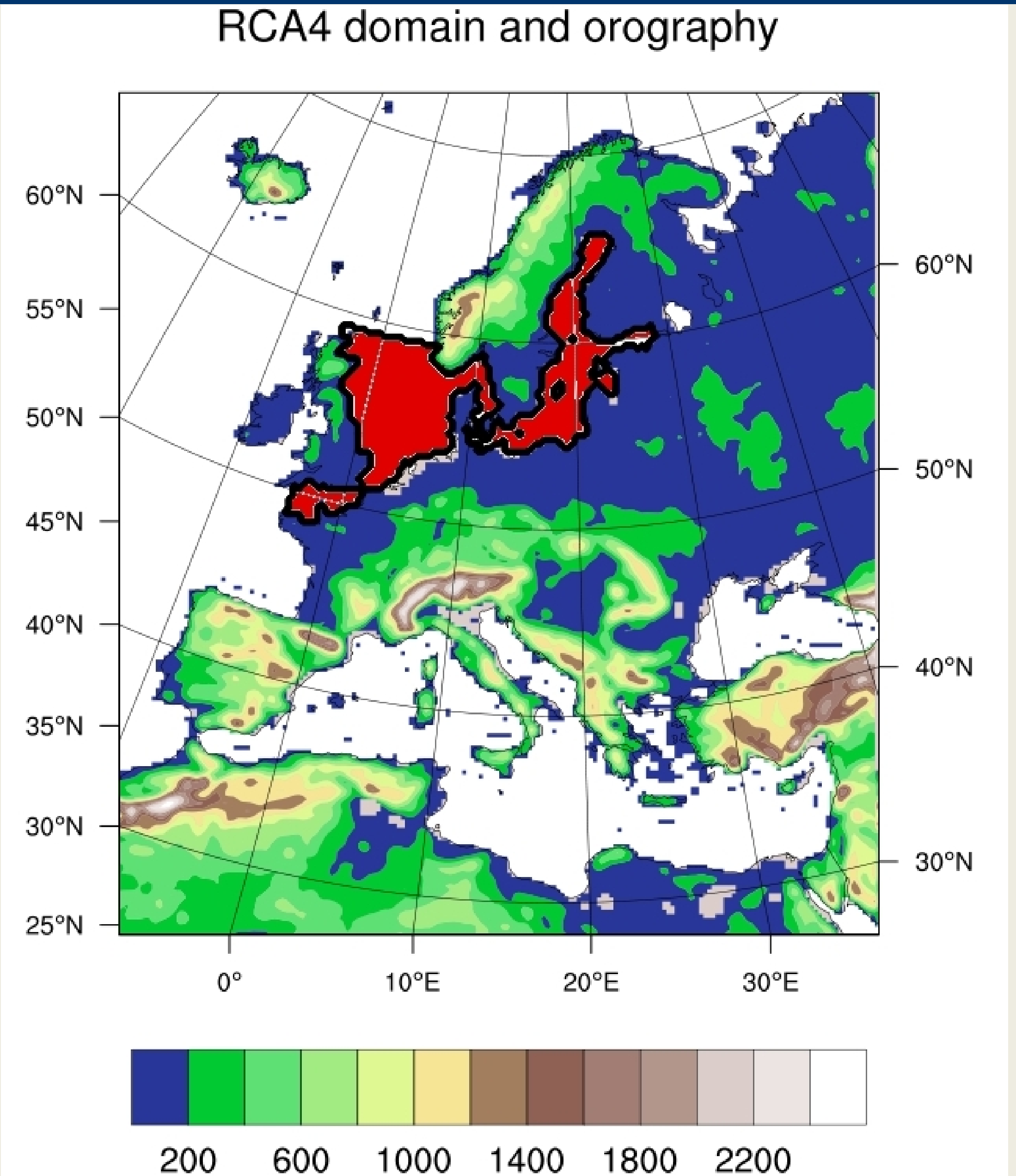


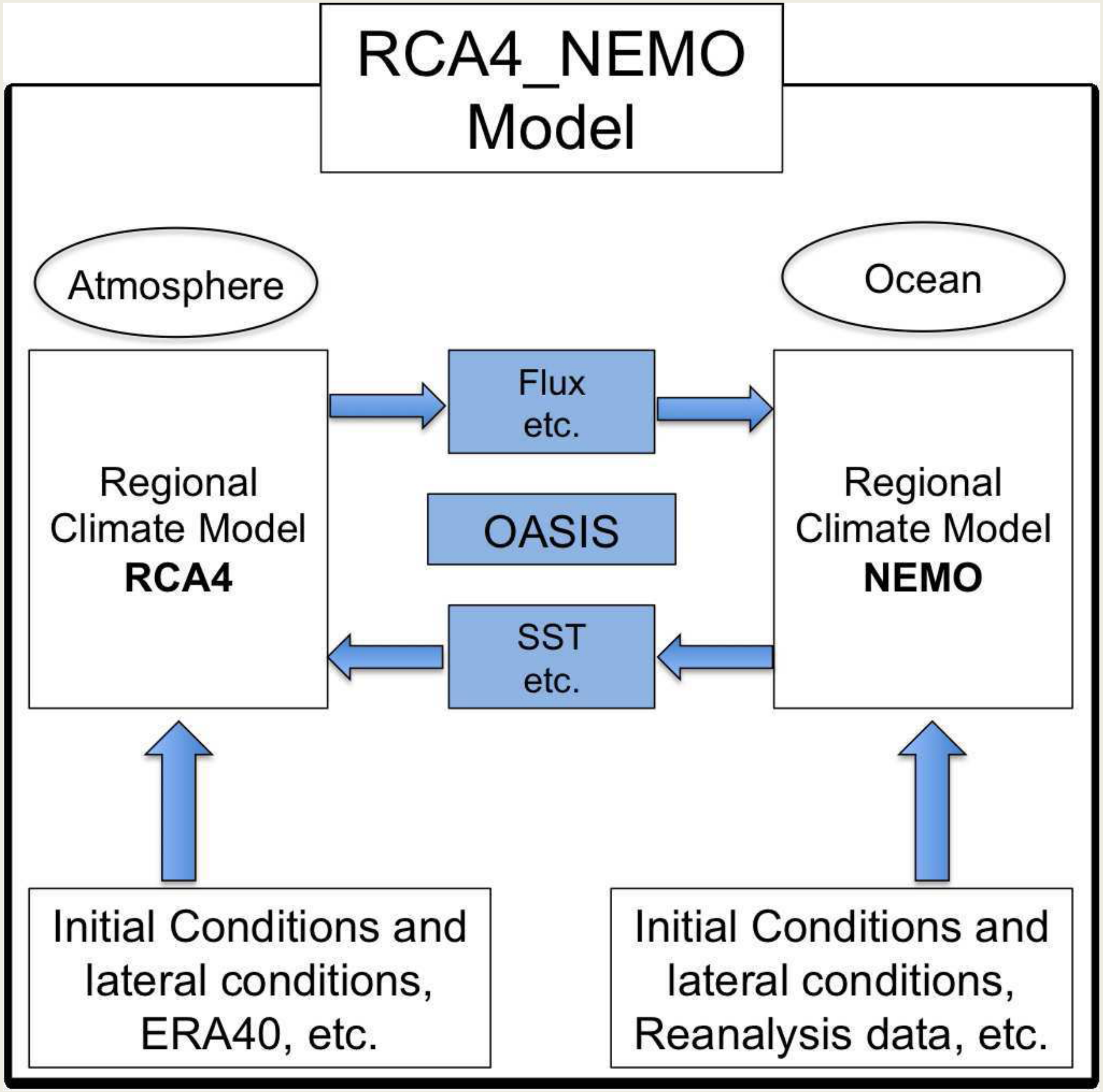
(Source: S. Schimanke, IMPROVE)

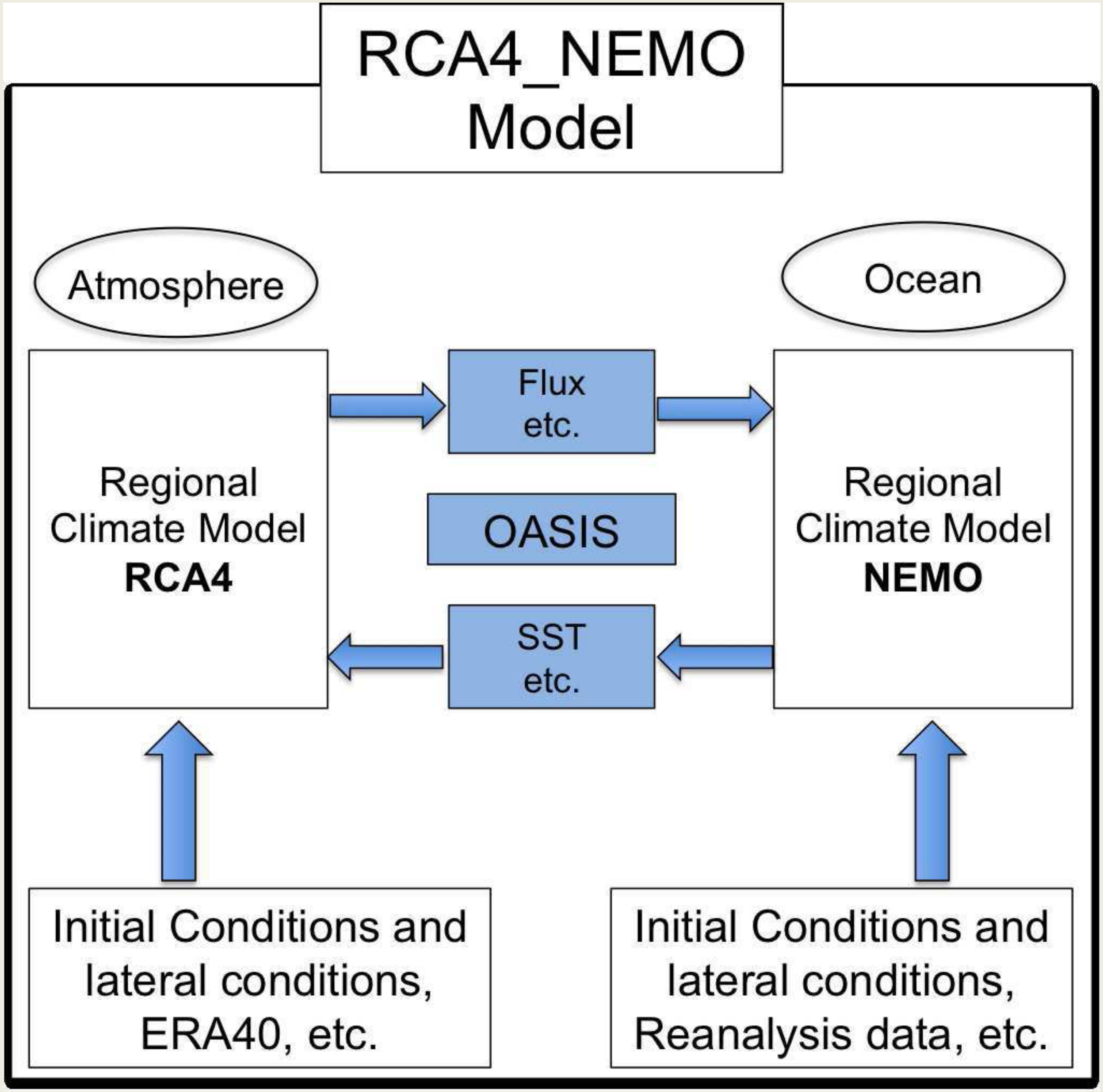
SMHI's regional climate models:

RCAO (Source: Döscher et al., 2002)

RCA-NEMO (Source: Wang et al., 2015)




RCA4_NEMO
Model
Atmosphere
Ocean
Regional
Climate Model
RCA4
Flux
etc.
OASIS
SST
etc.
Regional
Climate Model
NEMO
Initial Conditions and
lateral conditions,
ERA40, etc.
Initial Conditions and
lateral conditions,
Reanalysis data, etc.

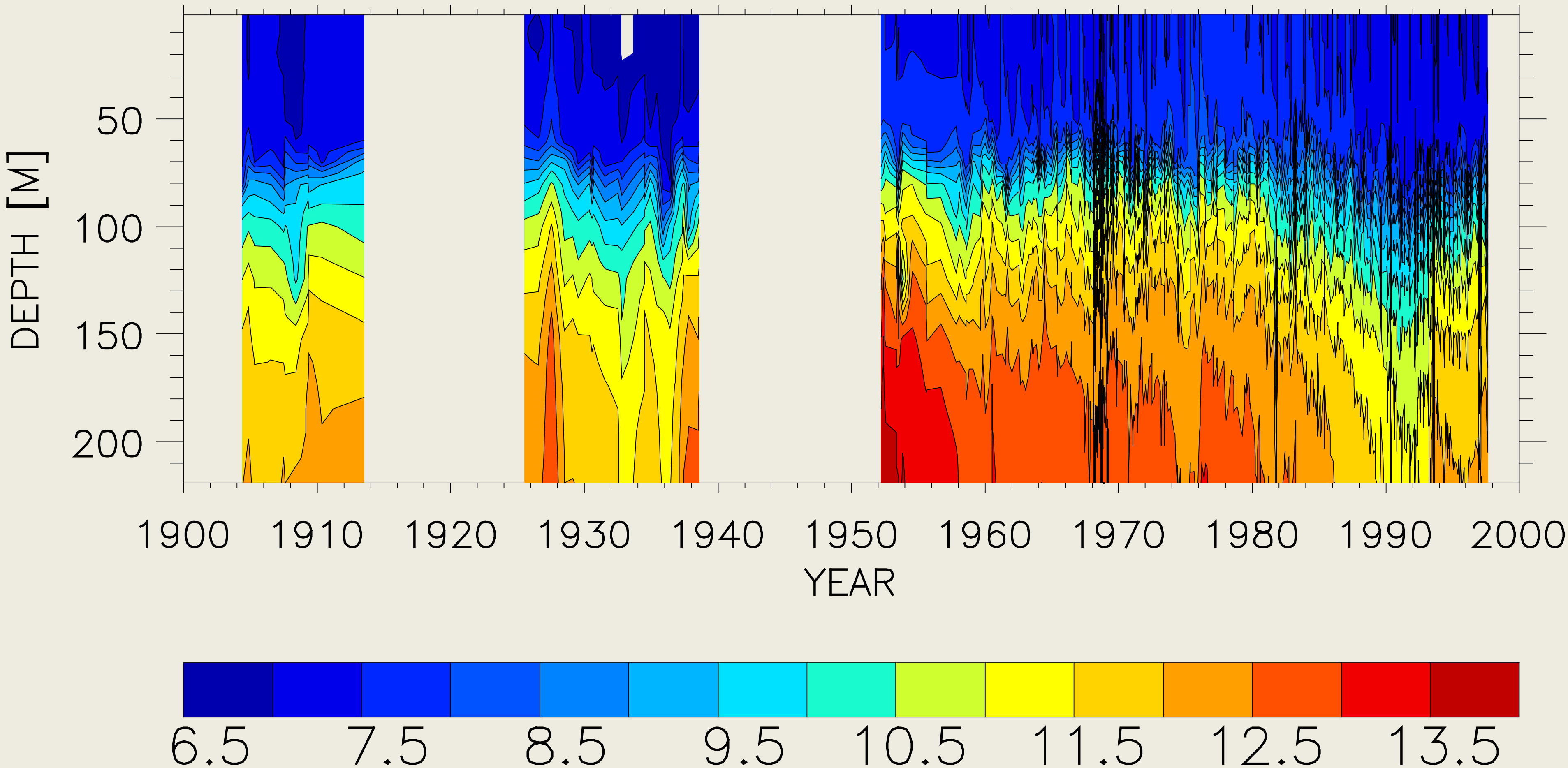


Additional components:

- sea ice
- waves
- marine biogeochemistry
- (marine food web)
- sediments
- land surface and hydrology
- lakes
- (dynamic land vegetation)
- (atmospheric chemistry)

Causes of decadal variability during the 20th century

Salinity as function of time and depth at Gotland Deep

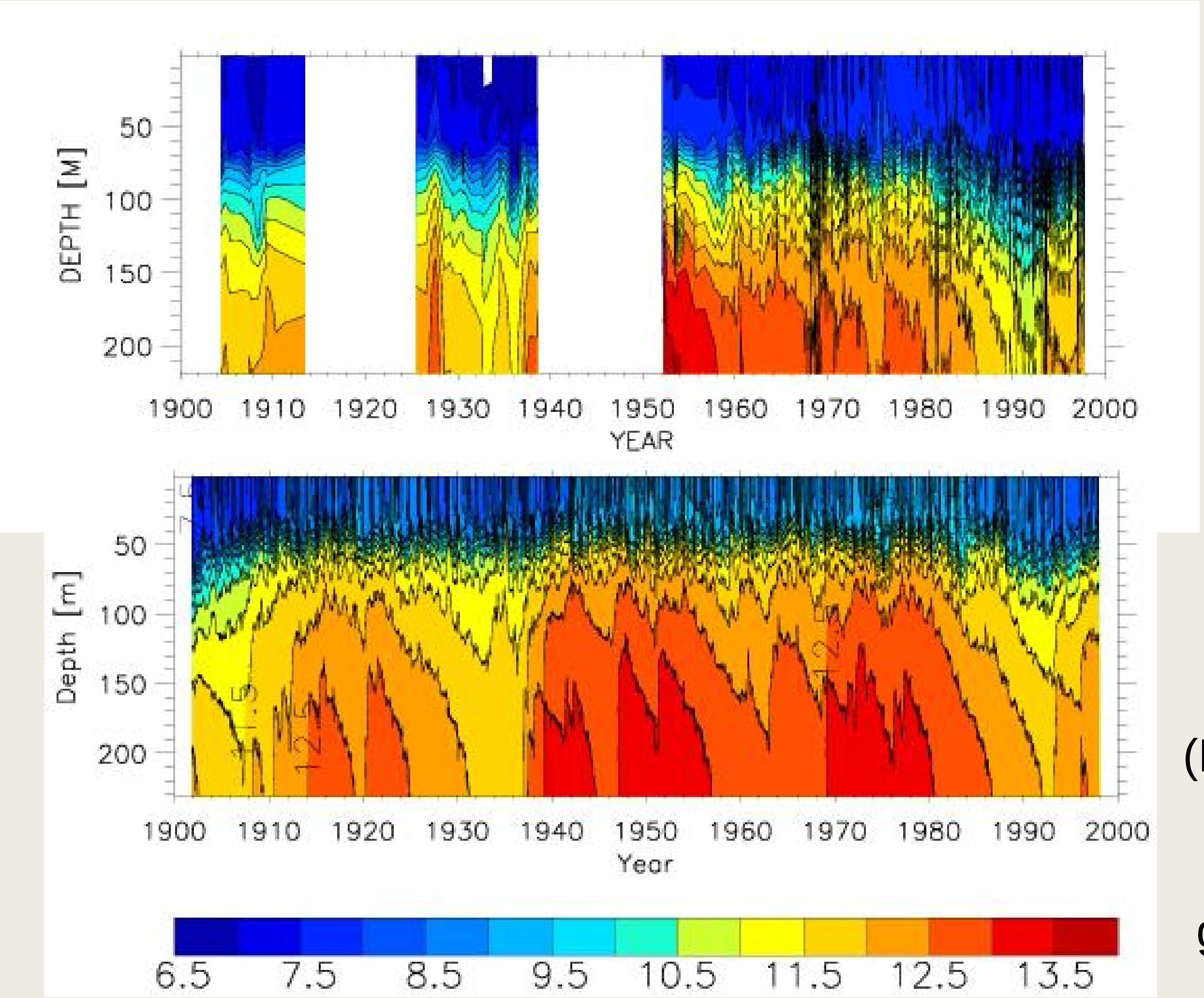


(Meier and Kauker, 2003a)

Salinity Gotland Deep

Data

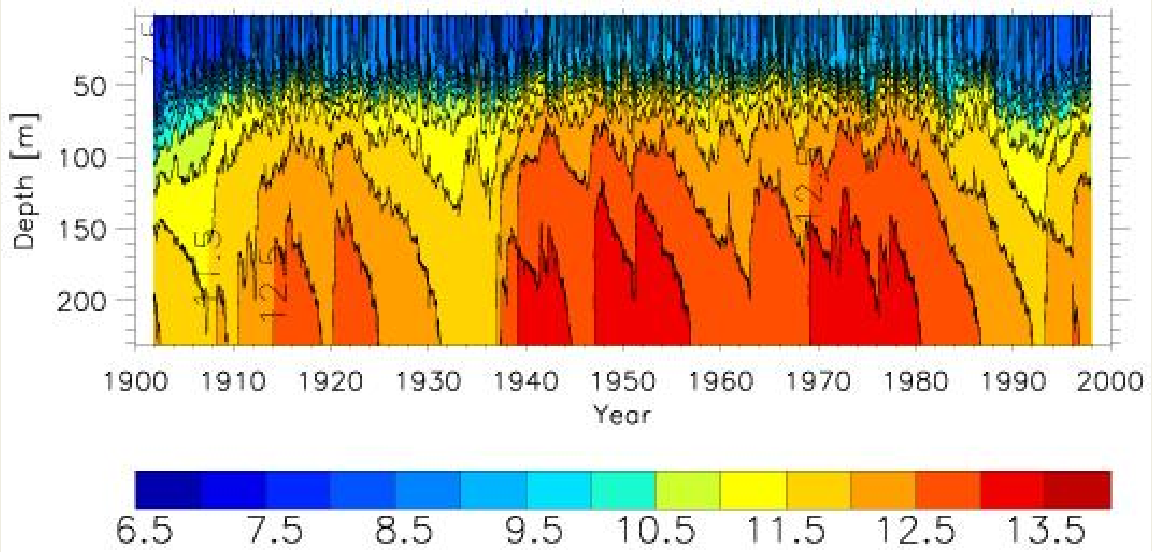
Model



(Meier, 2005)

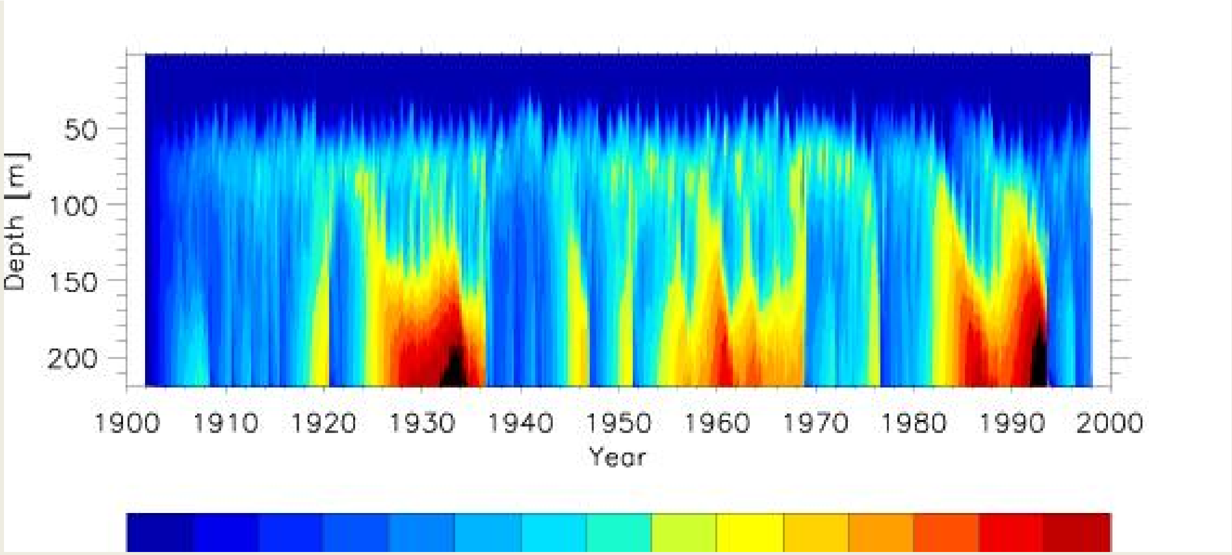
g kg^{-1}

Salinity



g kg^{-1}

Age



0.0 1.2 2.4 3.6 4.8 6.0 7.2 8.4 yr

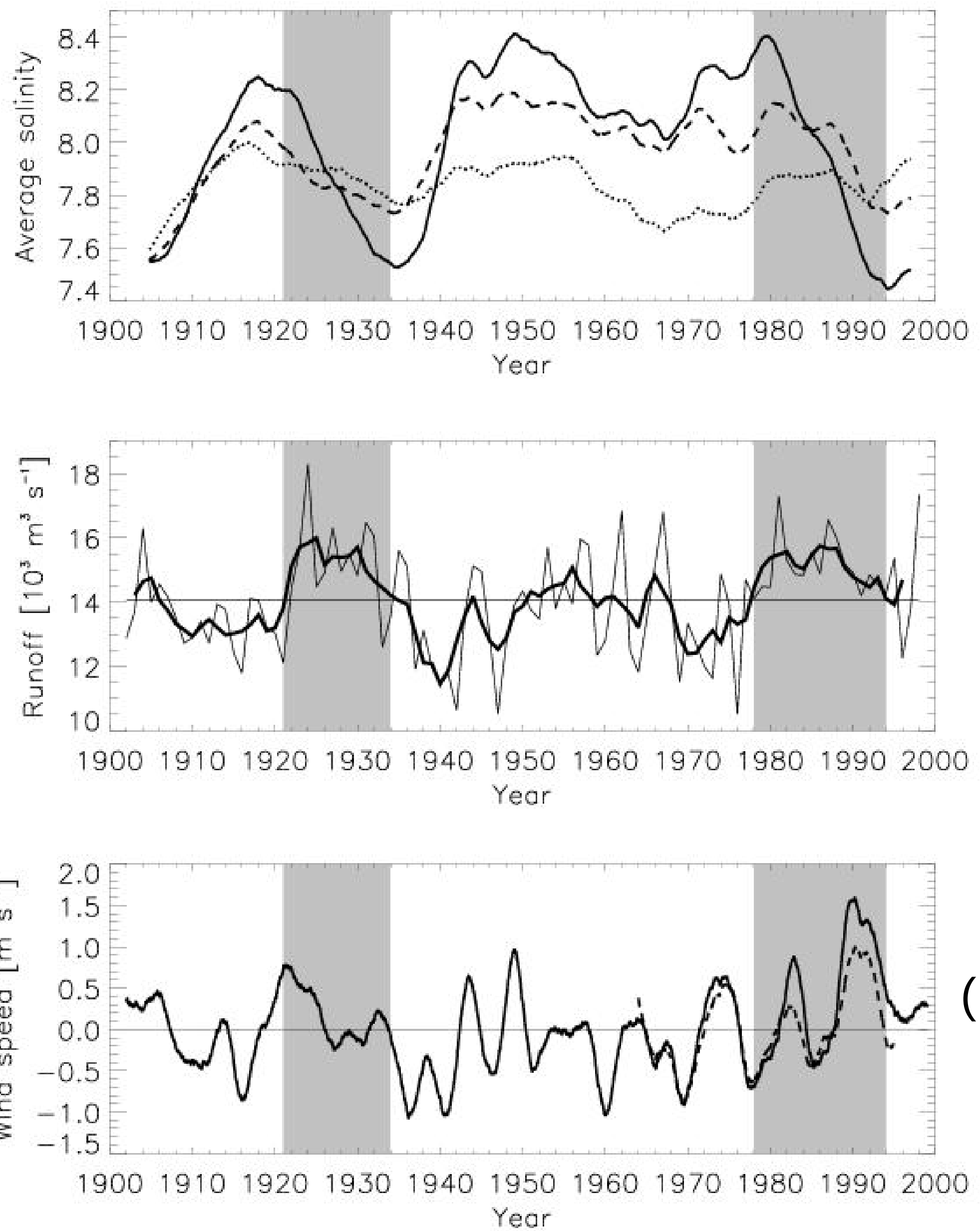
(Meier, 2005)

Stagnation periods

Salinity

Runoff

Wind



— 4-yr running mean

Stagnation periods are shaded

(Meier and Kauker, 2003a)

Summary of decadal variability

- half of the decadal variability of salinity is explained by accumulated freshwater inflow variations (Meier and Kauker, 2003a)
- another significant part is caused by the low-frequency variability of the wind (Meier and Kauker, 2003a)
- remainder might be caused by the high-frequency wind anomaly, i.e. specific atmospheric conditions causing major saltwater inflows (Lass and Matthäus, 1996)
- no impact of river regulation, sea ice (air temperature), sea level in Kattegat on decadal time scale

Climate reconstruction of the Baltic Sea region during the past 1000 years

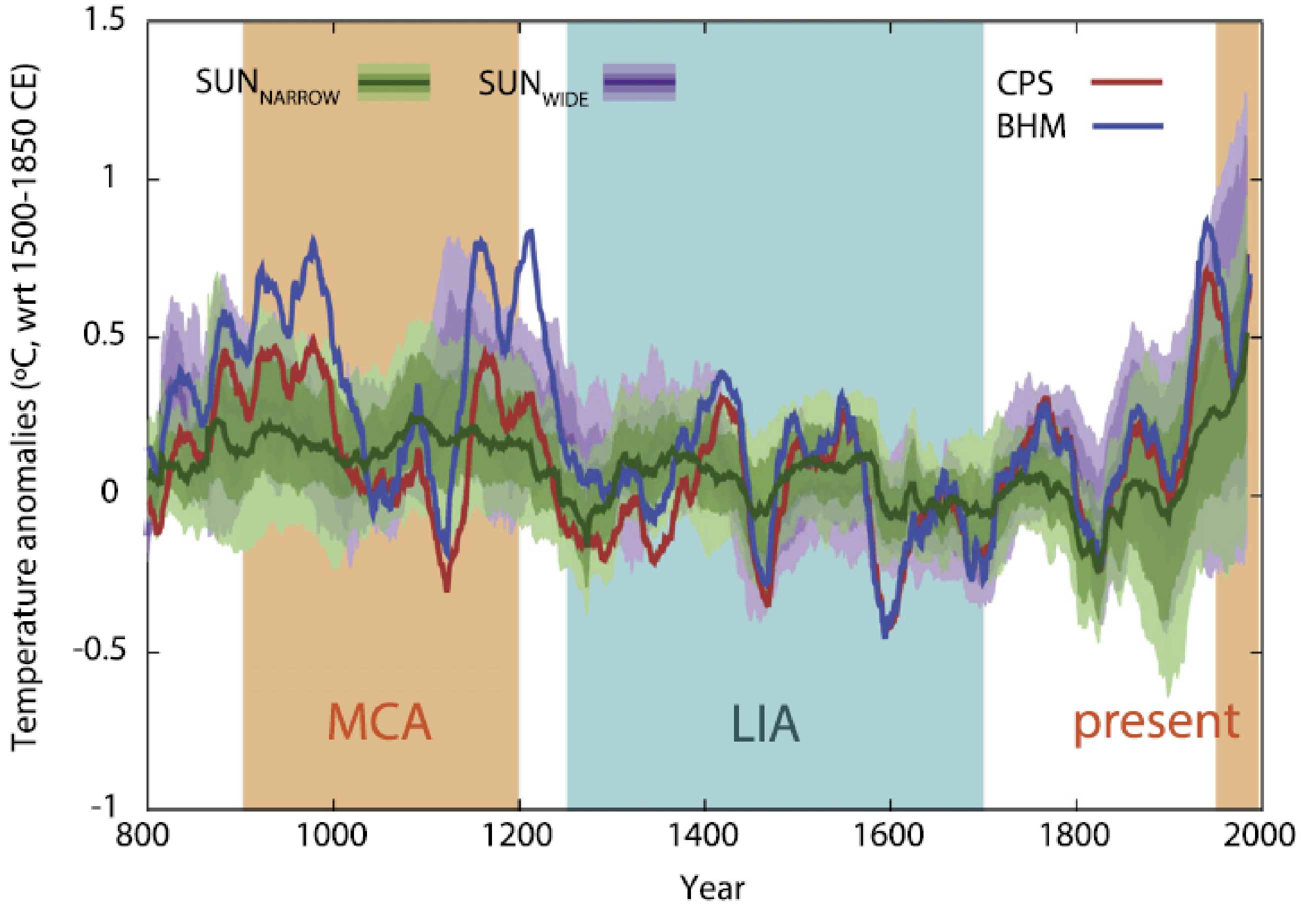


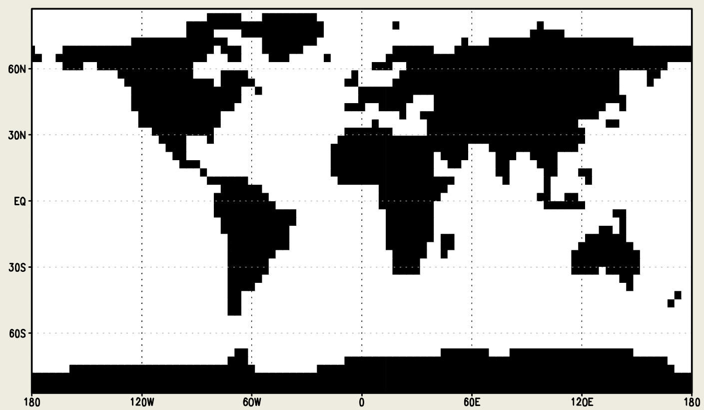
Figure 3. Simulated and reconstructed European summer land temperature anomalies (with respect to 1500–1850 CE) for the last 1200 yr, smoothed with a 31 yr moving average filter. BHM (CPS) reconstructed temperatures are shown in blue (red) over the spread of model runs. Simulations are distinguished by solar forcing: stronger (SUN$_{WIDE}$, purple; TSI change from the LMM to present >0.23%) and weaker (SUN$_{NARROW}$, green; TSI change from the LMM to present <0.1%). The ensemble mean (heavy line) and the two bands accounting for 50% and 80% (shading) of the spread are shown for the model ensemble (see SOM for further details).

(Source: Luterbacher et al. 2016)

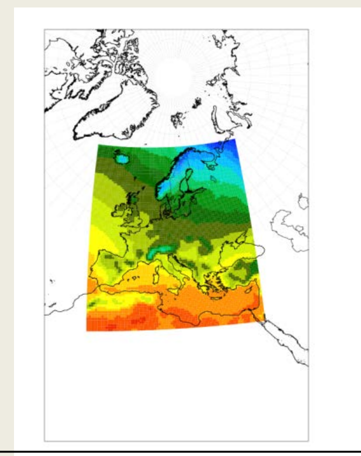
- Transient simulations of the last millennium (950-1997) with the global model and RCA3
- Solar variability, orbital parameters and GHG as forcing parameters
- 2 times 50 years sensitivity studies with RCO for selected time periods

(Source: Schimanke et al., 2012; Clim. Past)

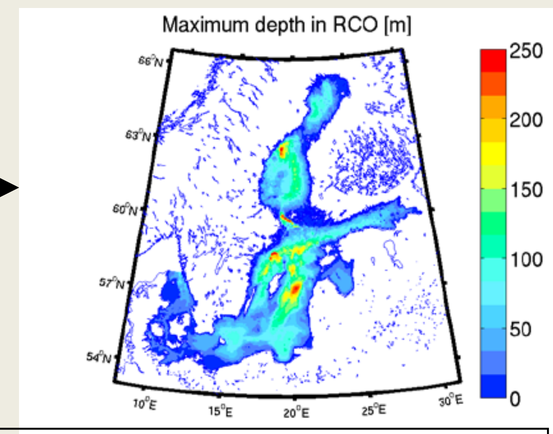
ECHO-G



RCA3



RCO



T30 ≈ 3.75° x 3.75°	0.44°x0.44° (~50km)	2nm (3.7km x 3.7km)
19 vertical levels	24 vertical levels	83 vertical levels
HOPE-G (2.8°x2.8°)		+ Biogeochemical model SCOBI

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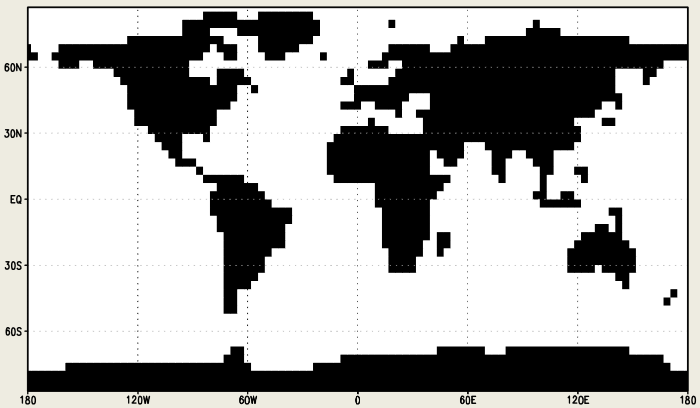
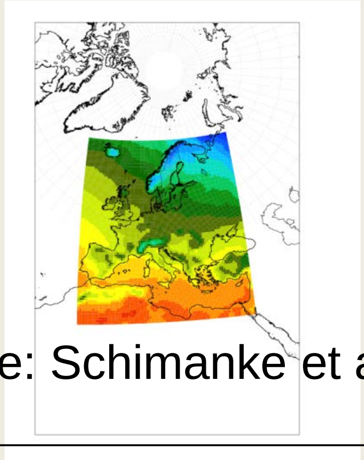
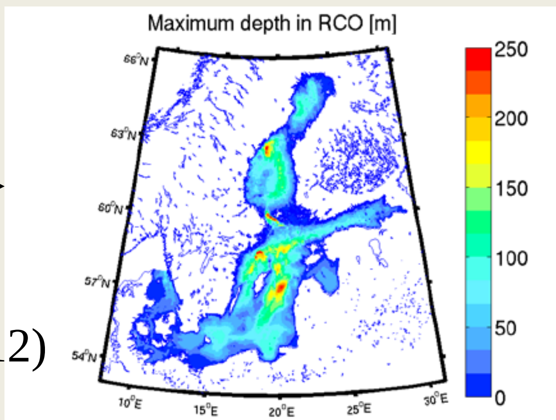


RCA3



(Source: Schimanke et al., 2012)

RCO



ECHO-G	RCA3	RCO
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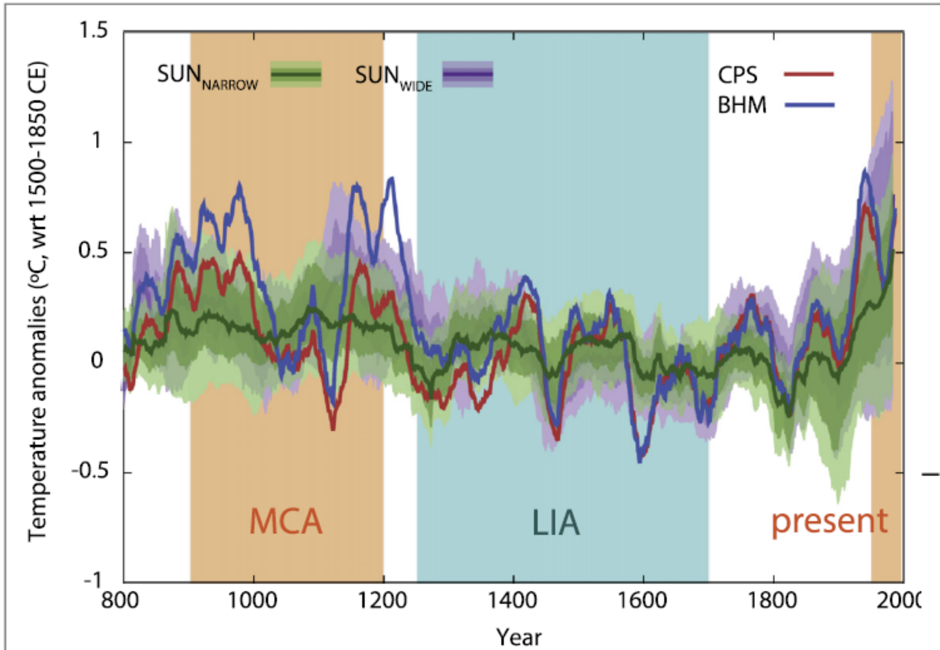

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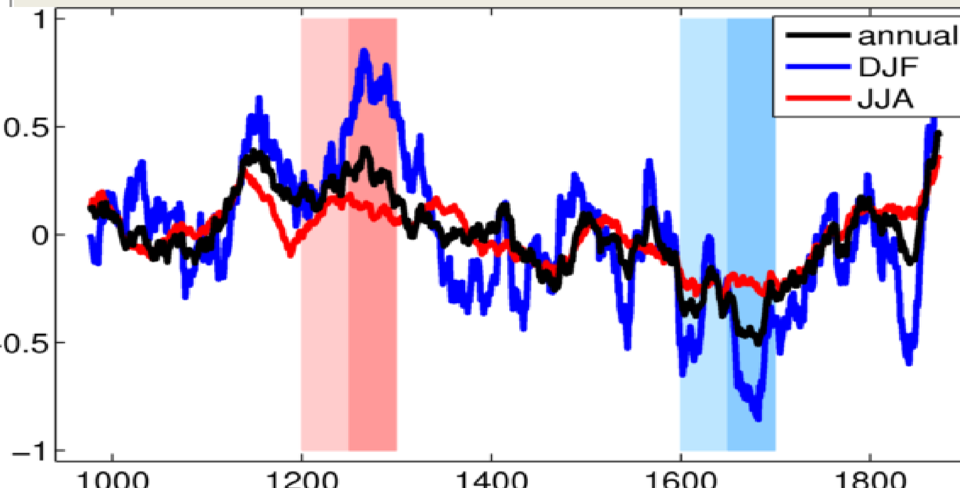
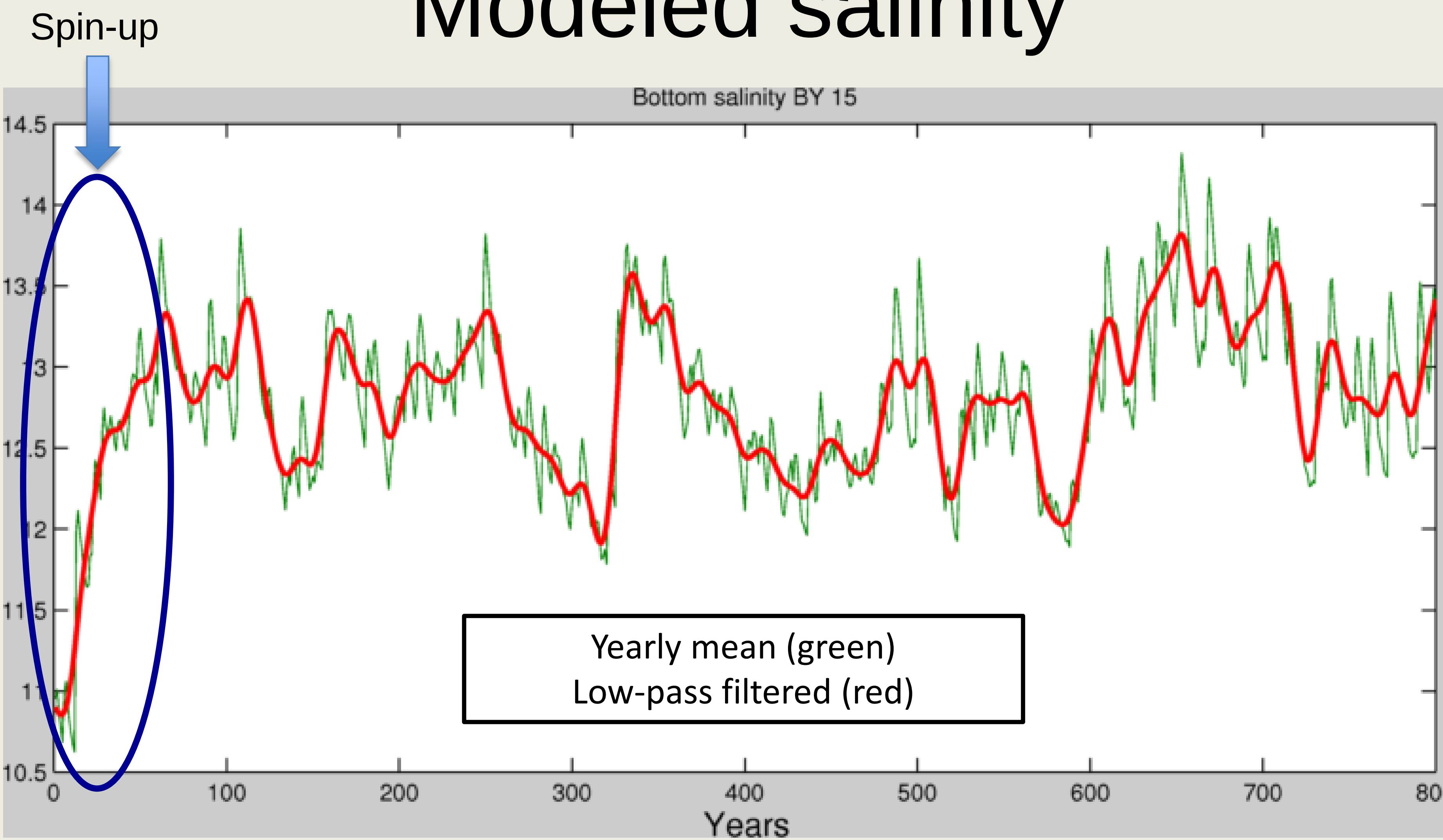


2 m-temperature anomaly w.r.t. the pre-industrial mean (950–1900) averaged over the Baltic Sea region

(Source: Luterbacher et al. 2016)

(Source: Schimanke et al., 2012)

Modeled salinity



(Schimanke and Meier, 2016)

How exceptional are long lasting stagnation periods in the Baltic Sea from a model perspective?

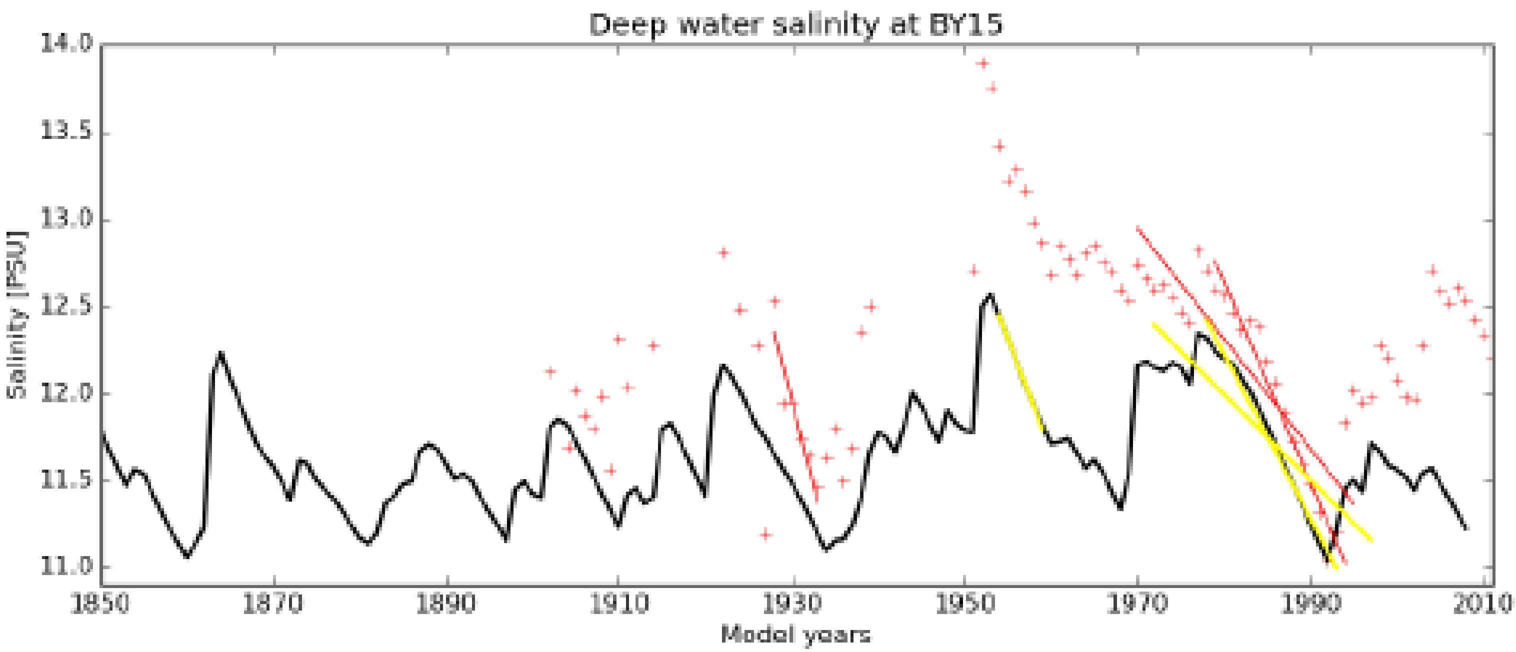


FIG. 2: Annual mean salinity of the hindcast simulation at BY15 in 200 m and strongest linear reductions in salinity (yellow lines) for periods of 5, 15, and 25 years. Observations based on BED and SHARK data are shown as red crosses, and corresponding maximum negative trends as red lines.

(Schimanke and Meier, 2016)

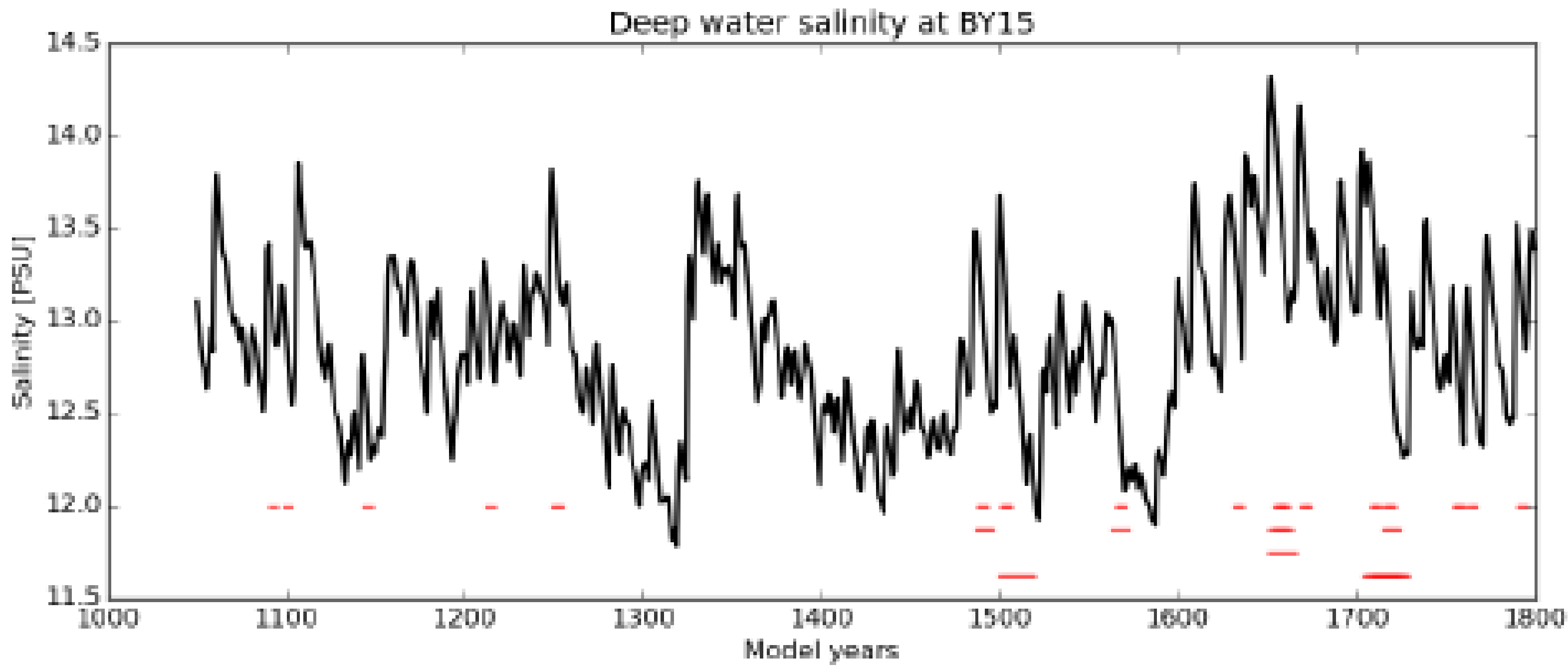


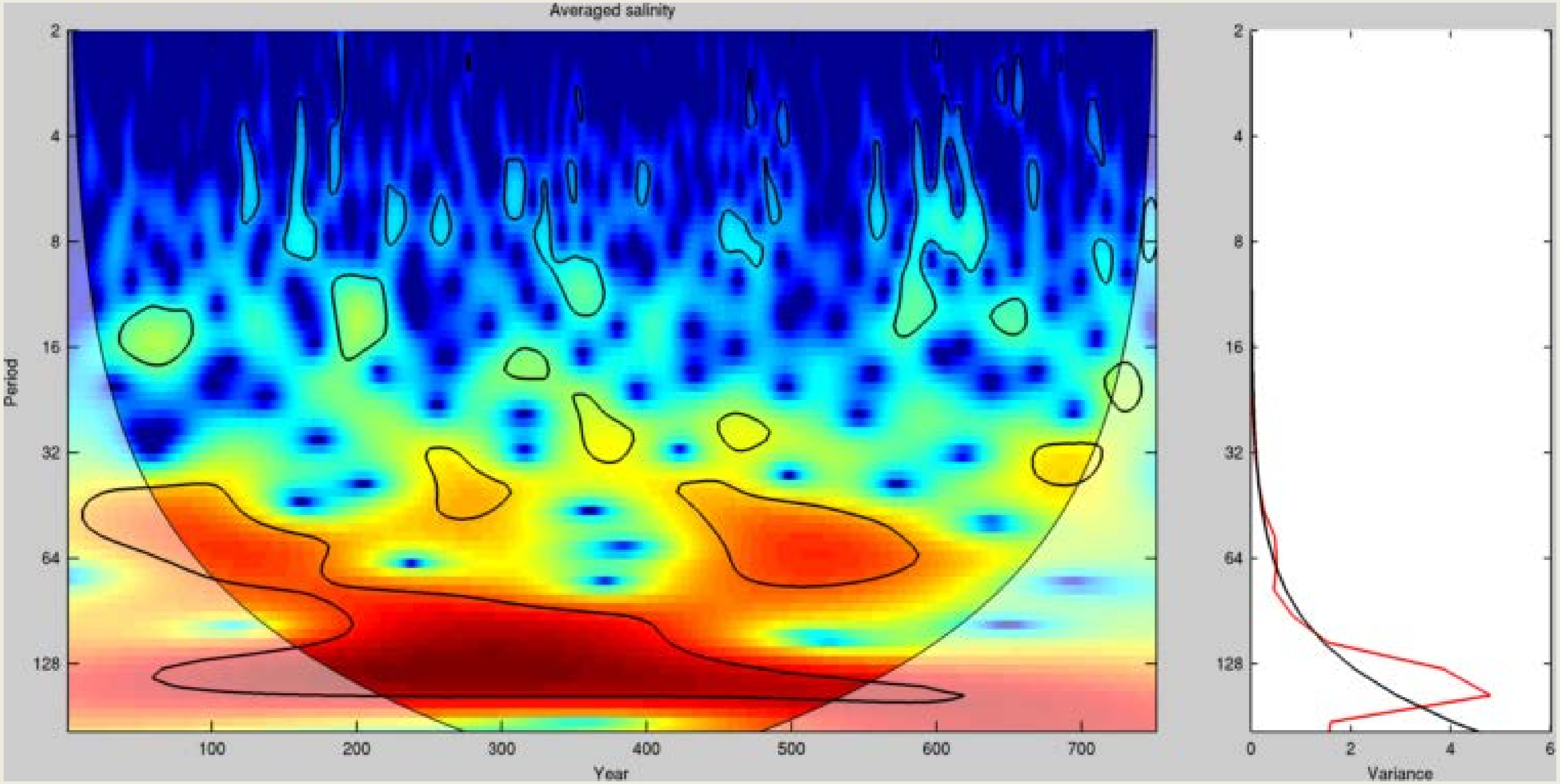
FIG. 3: Deep water salinity at BY15 in the long climate simulation (black line). The red lines indicate time slices with a reduction in salinity with a regression at least as big as in the hindcast simulation for 5-, 10-, 15- and 20-year periods of decrease.

(Schimanke and Meier, 2016)

- Stagnation periods over 10 years are not exceptional
- Longer lasting freshening periods (16 years) are unlikely from the model perspective
- 62% of the long-term salinity variability can be explained by runoff, temperature, wind and NAO fluctuations

Wavelet analysis

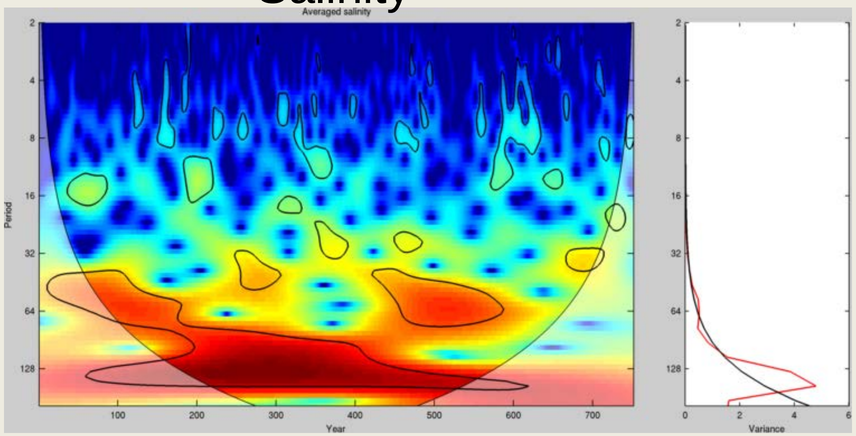
Time series analysis to detect power on different periods which can be non-stationary. Reddish means more power, black line indicates 95% significant level. Outside the cone of influence results are not reliable.



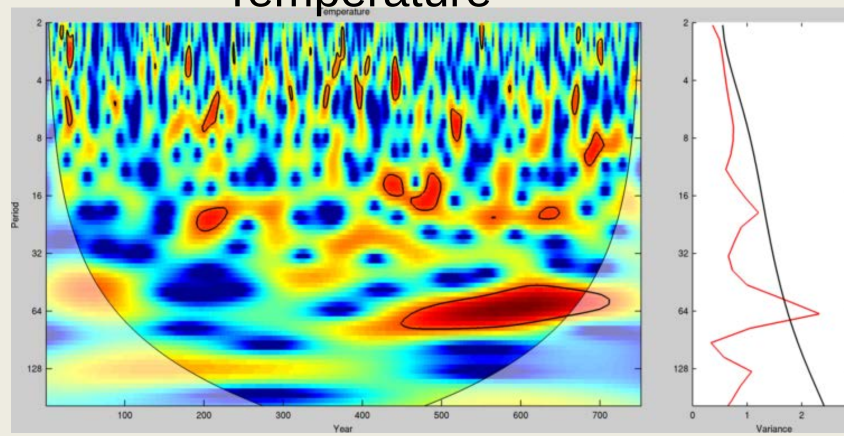
(Schimanke and Meier, 2016)

Wavelets

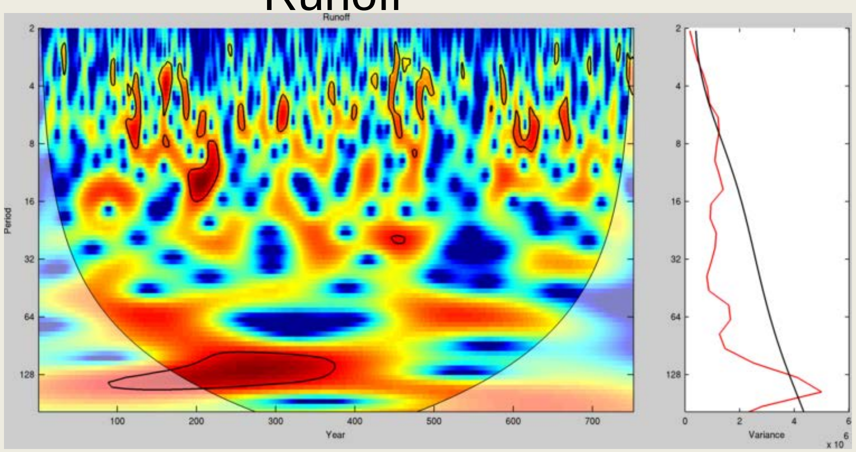
Salinity



Temperature



Runoff

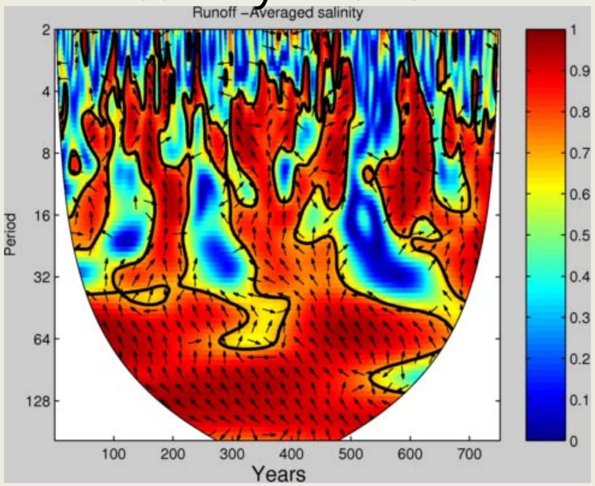


- Parameters have power on similar periods and time slices

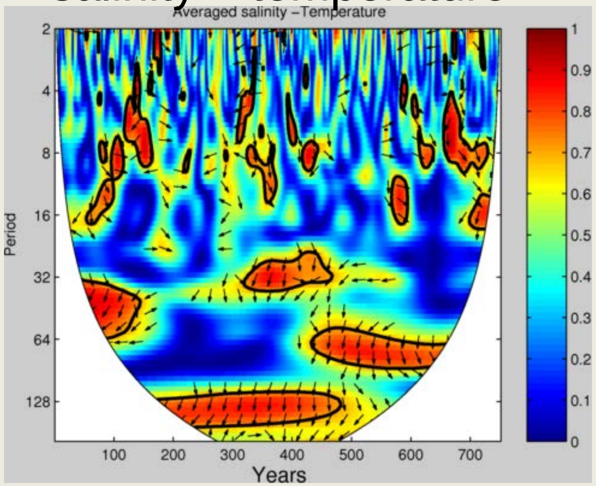
(Schimanke and Meier, 2016)

Wavelet coherence

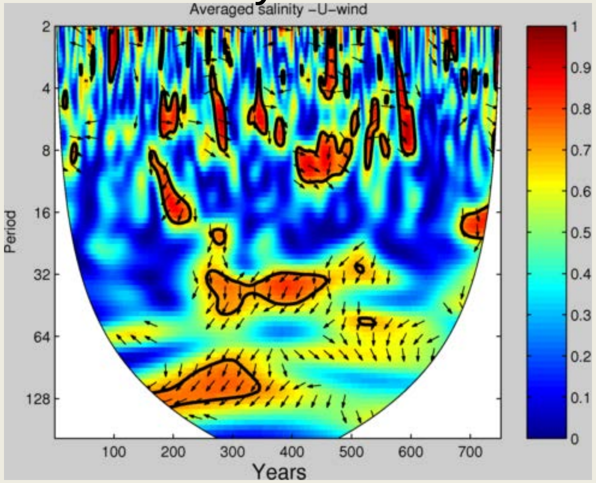
salinity – runoff



salinity – temperature

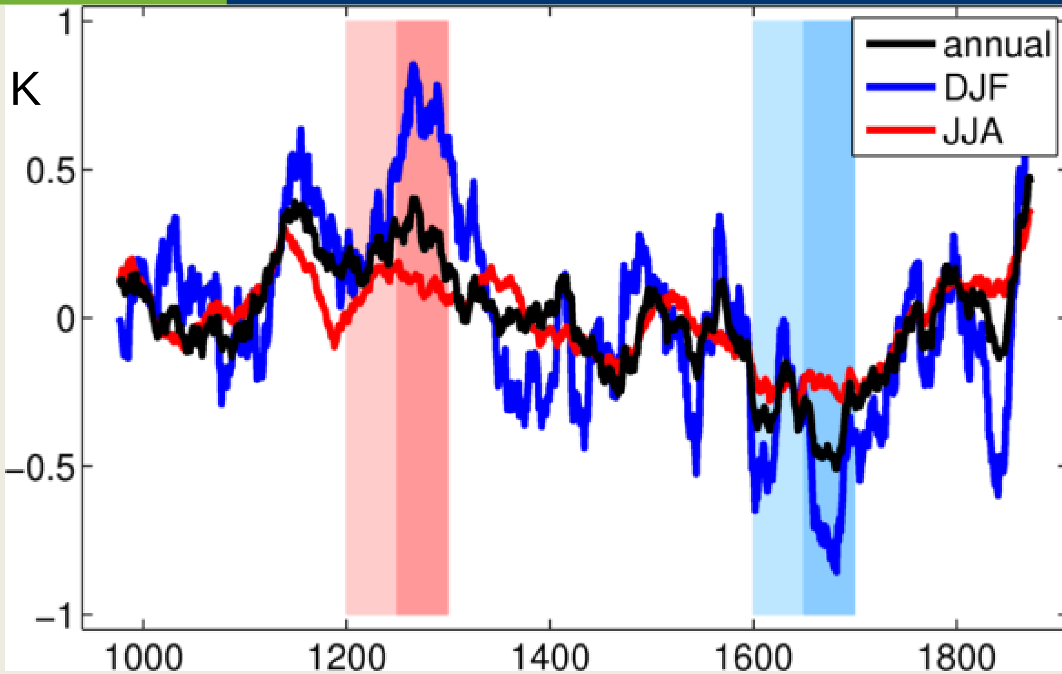


salinity – u-wind



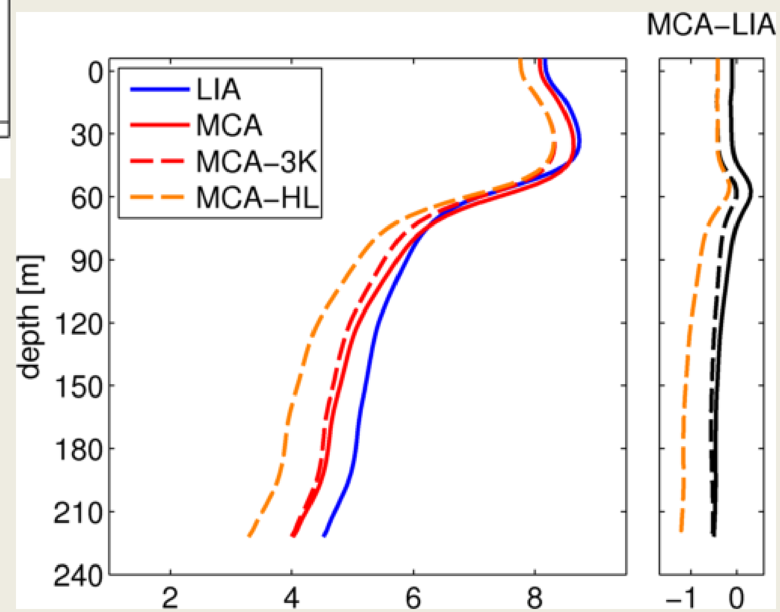
- no coherence for periods shorter than 4 years
- significant correlation of salinity and runoff for all periods larger than 4 years
- weaker coherence with temperature and u-wind
- enhanced power and coherence for frequencies larger 50 years must be investigated in more detail

(Schimanke and Meier, 2016)



2 m-temperature anomaly w.r.t. the pre-industrial mean (950–1900) averaged over the Baltic Sea region

50-year mean vertical oxygen concentration profiles at Gotland Deep



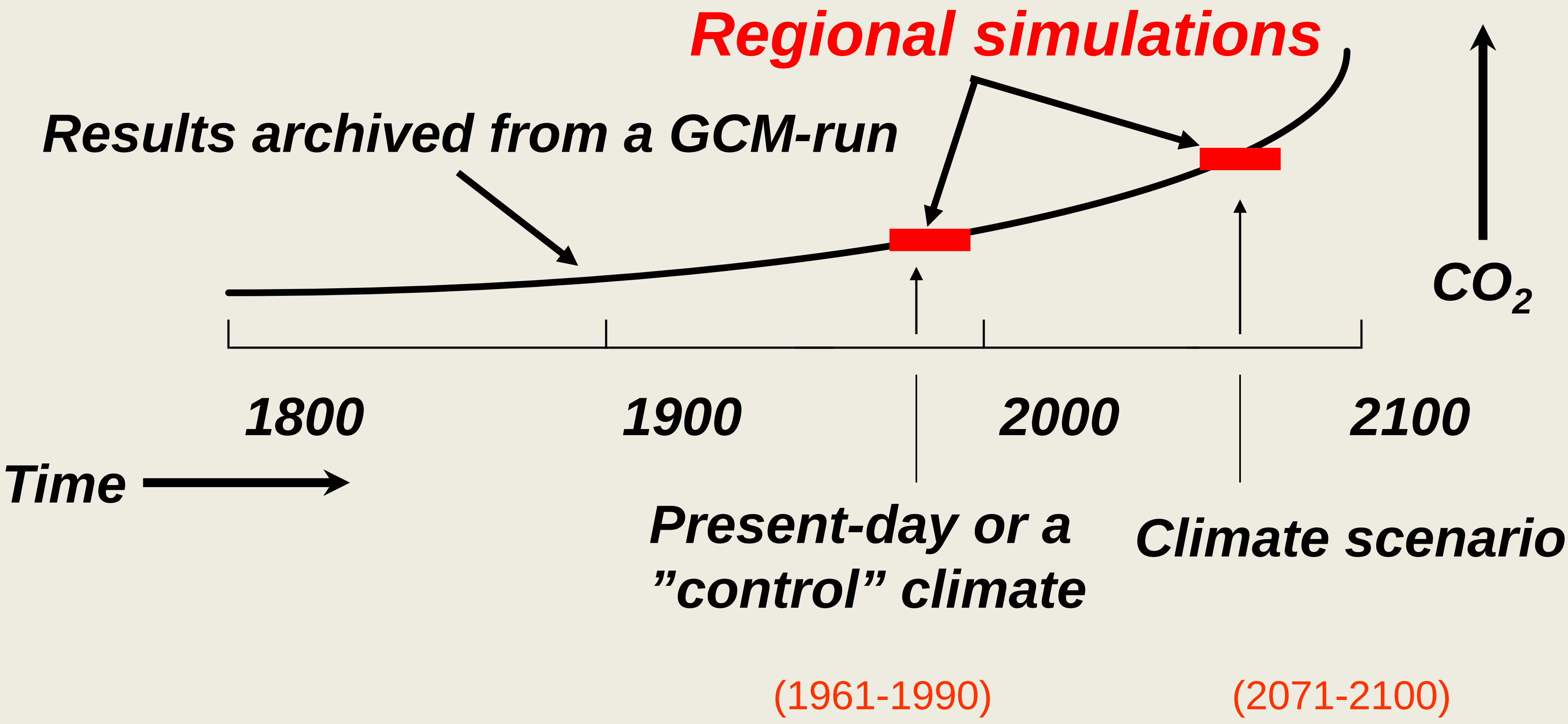
(Source: Schimanke et al., 2012; Clim. Past)

Oxygen (ml l^{-1})

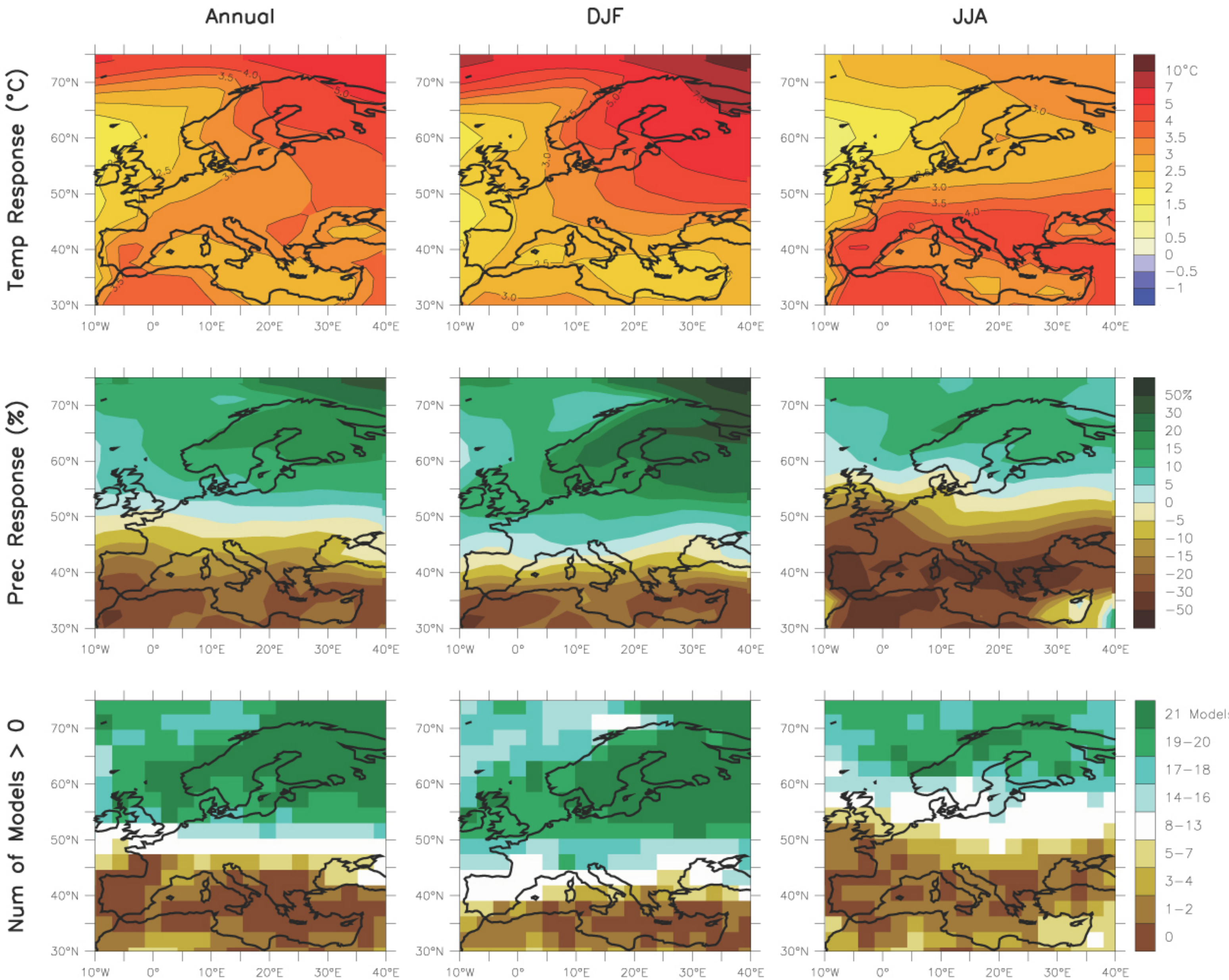
Scenario simulation for the 21st century

The first generation of scenario simulations for the Baltic Sea (IPCC 2001, B2, A2)

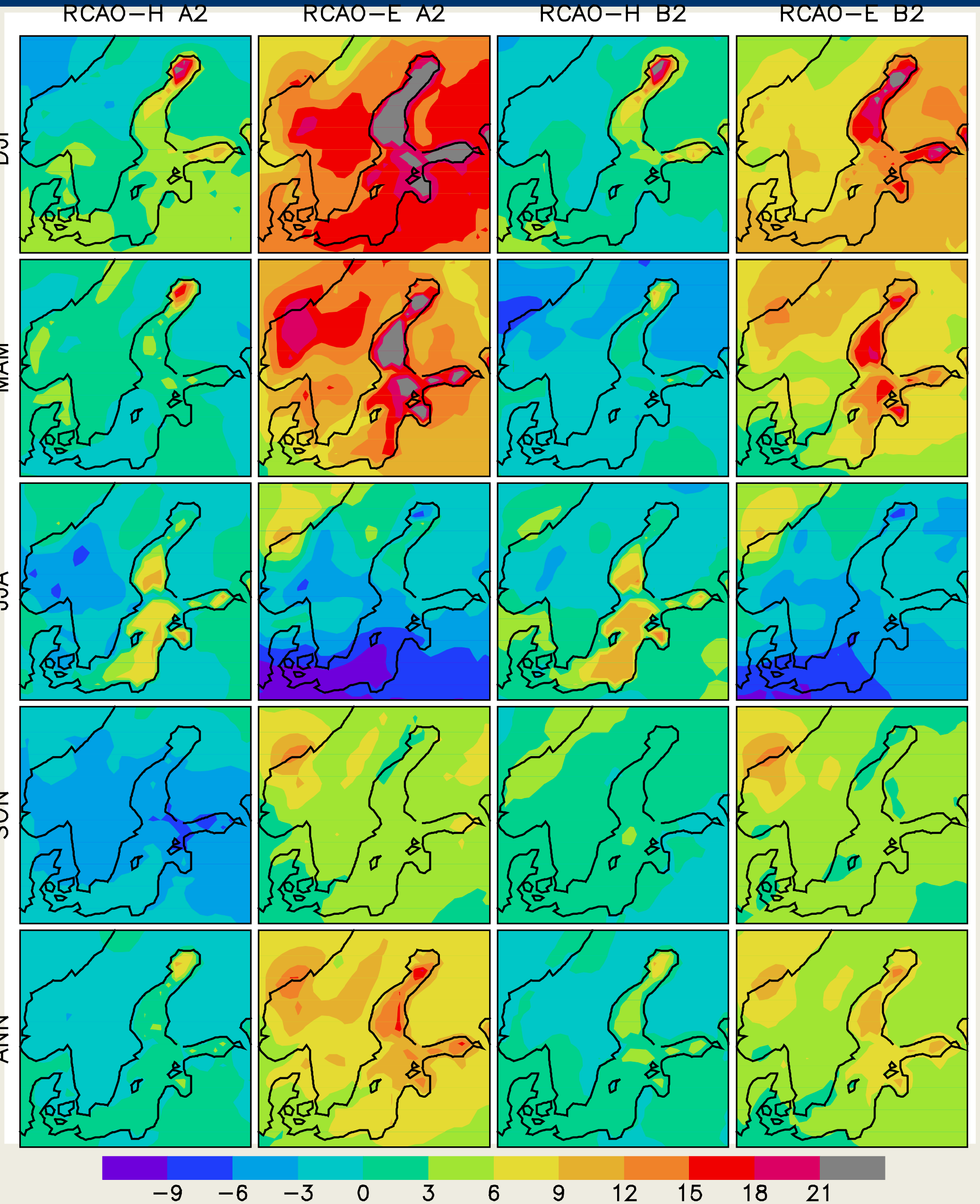
Regionalization is done for ”time-slices” from GCMs

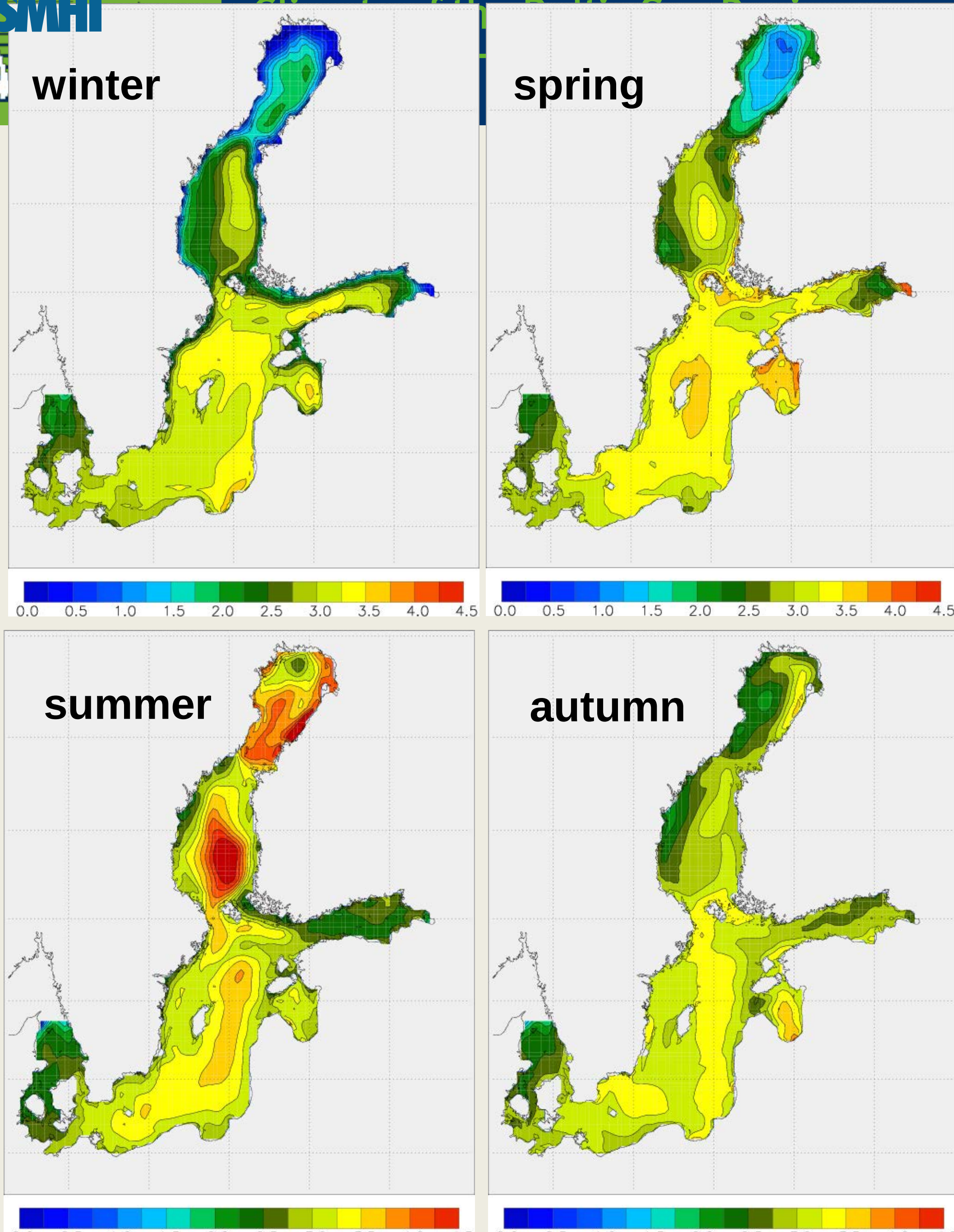


Temperature and precipitation changes over Europe in the A1B model ensemble



Wind speed changes [%]

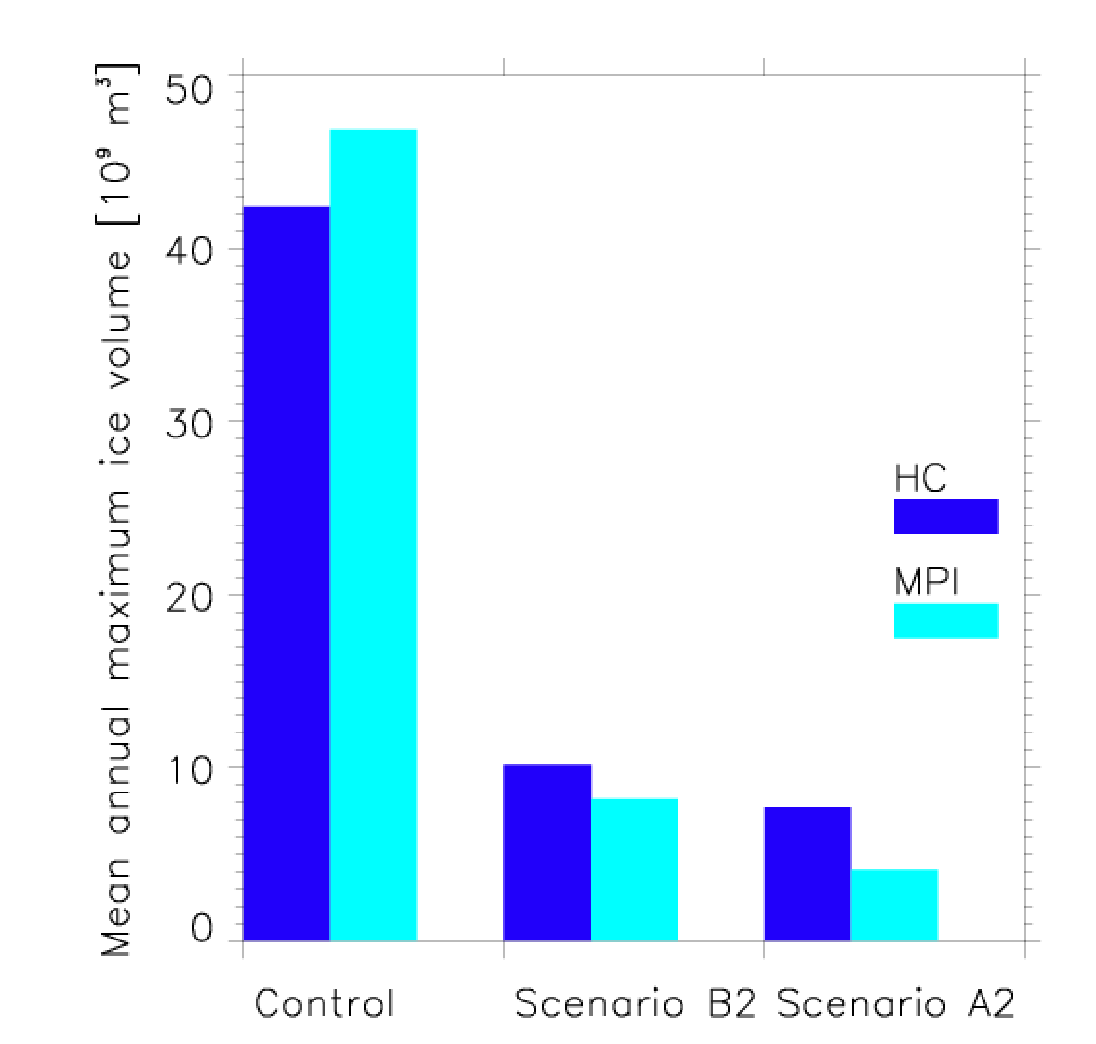




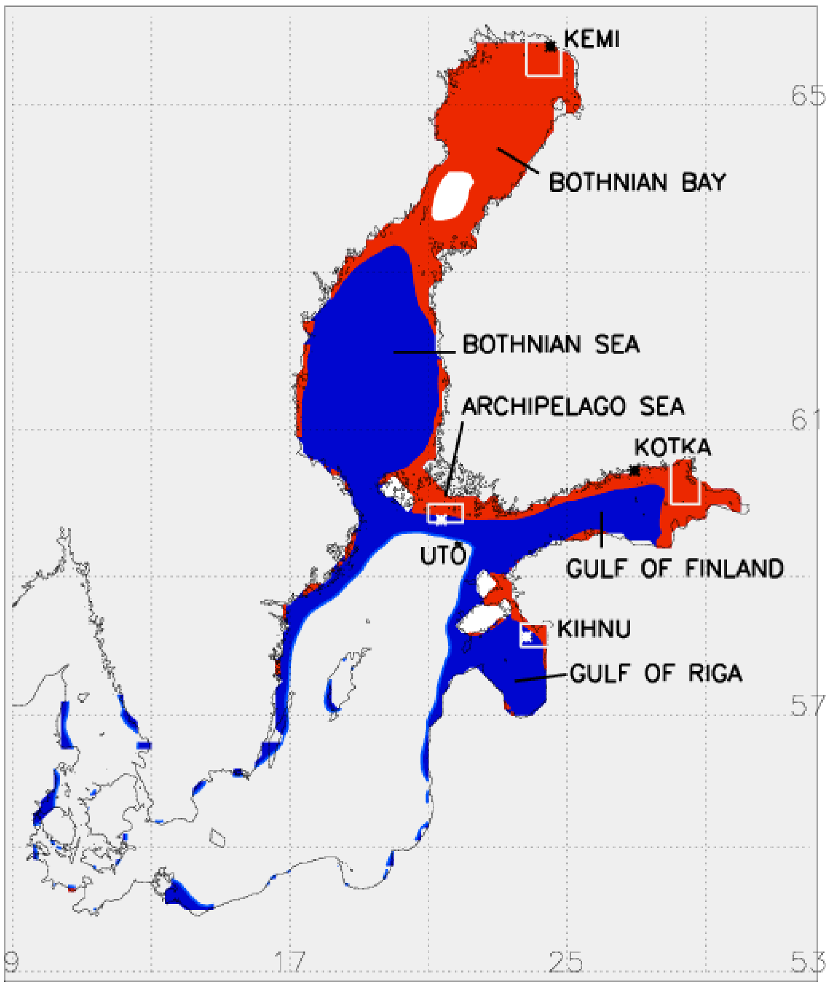
Annual mean sea surface temperature change: + 2-4°C

Seasonal mean SST differences between the ensemble average scenario and simulated present climate (in °C): DJF (upper left), MAM (upper right), JJA (lower left), and SON (lower right) (Meier, 2006).

Mean annual maximum ice volume in control and scenario experiments



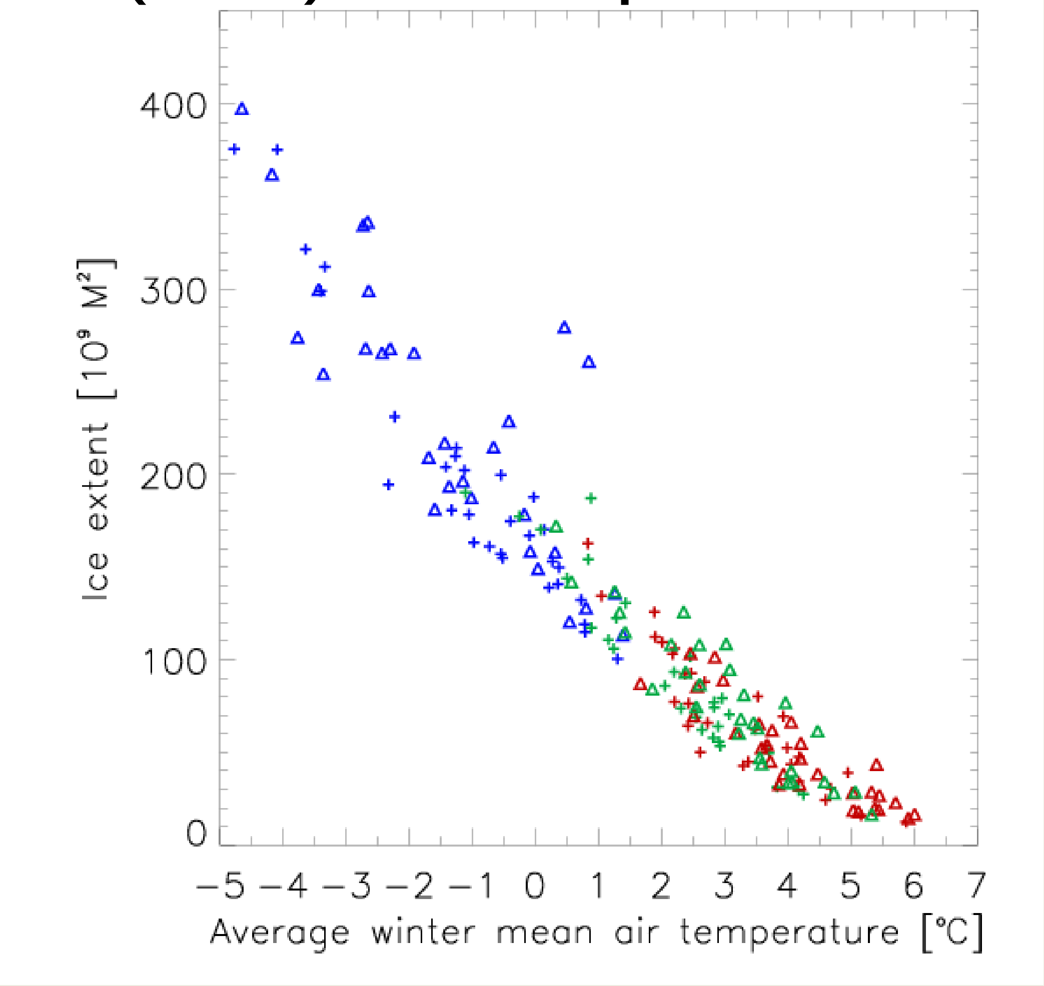
Mean maximum ice cover in control (blue) and scenario (red)



Mean maximum ice extent change: - 60-70%

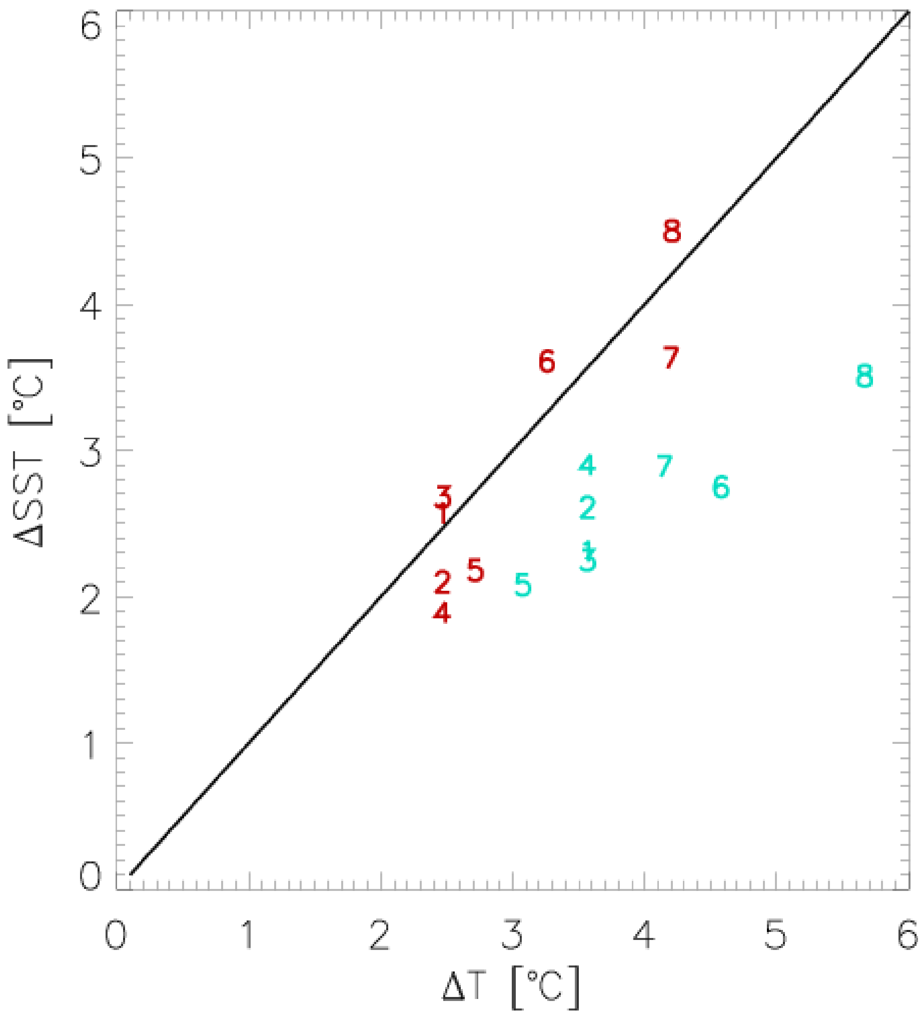
(Meier et al., 2004c)

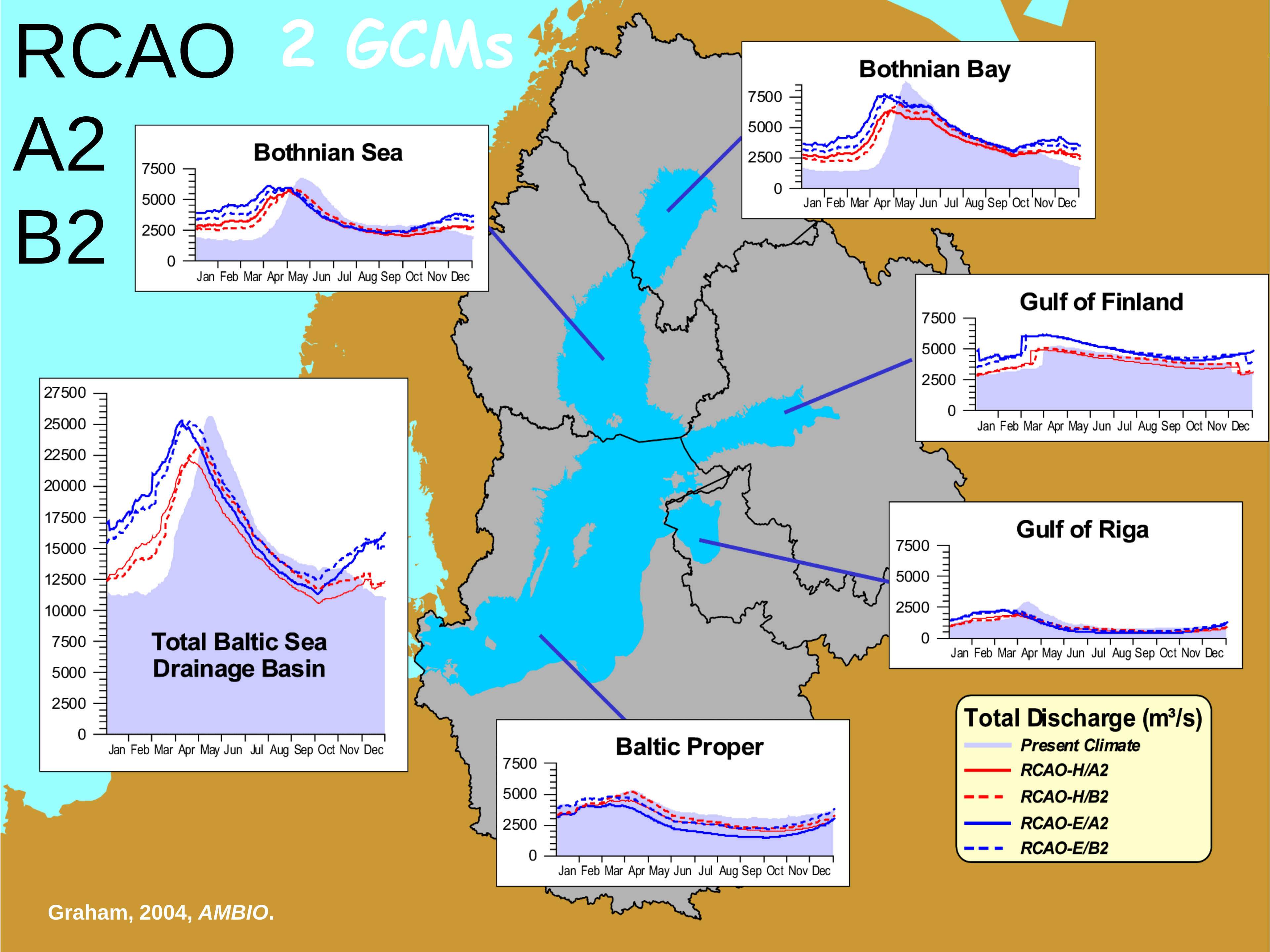
Scatterplot of annual maximum ice extent and winter mean (DJF) air temperature at Stockholm



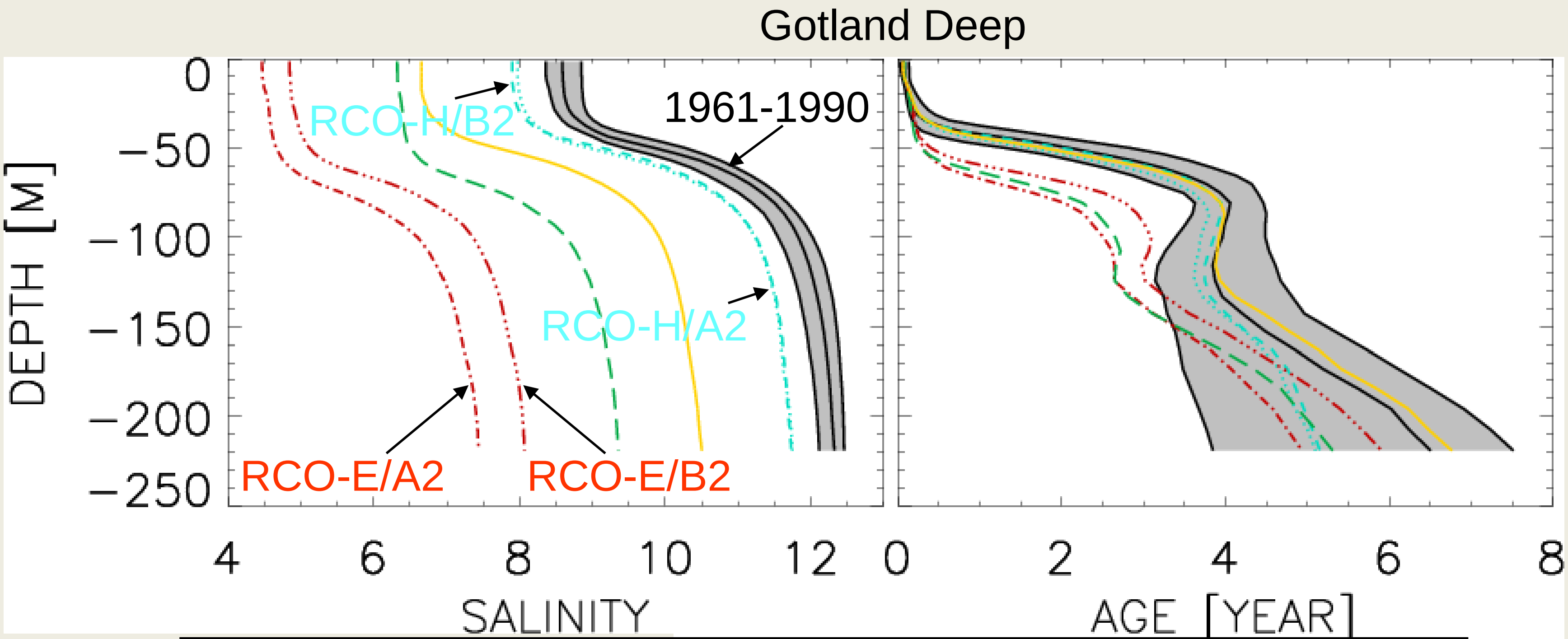
RCAO-H (plus signs), RCAO-E (triangles), control (blue), B2 (green), A2 (red)

SST changes versus air temperature changes for winter (blue) and summer (red)



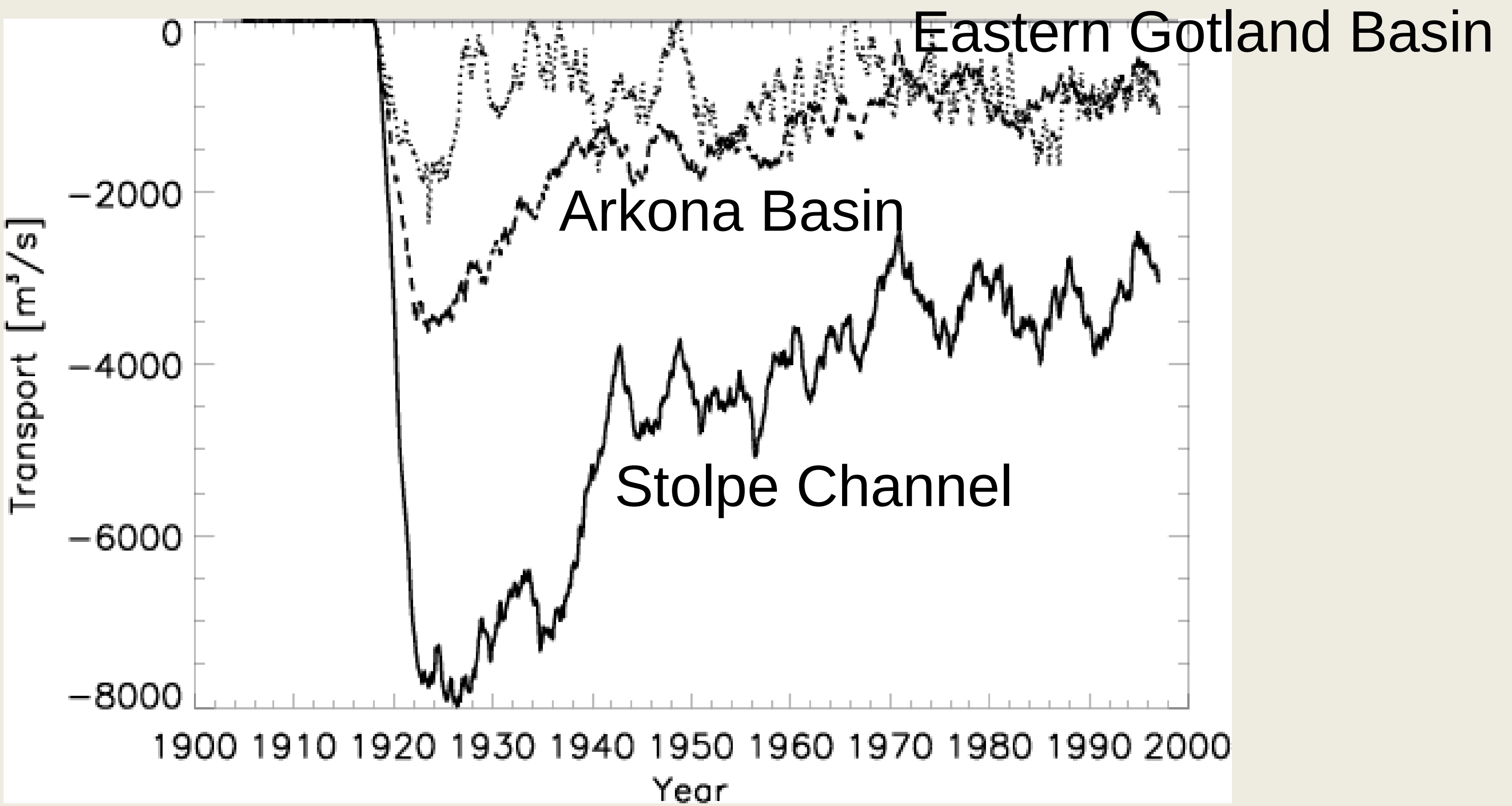

RCAO
A2
B2
2 GCMs
Bothnian Bay
Bothnian Sea
Gulf of Finland
Gulf of Riga
Baltic Proper
Total Baltic Sea Drainage Basin
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Total Discharge (m³/s)
Present Climate
RCAO-H/A2
RCAO-H/B2
RCAO-E/A2
RCAO-E/B2
Graham, 2004, AMBIO.

Median salinity and age profiles for 1961-1990 at Gotland Deep



Present climate (median, 1. and 3. quartiles)
RCO-H/B2, A2 scenarios
RCO-E/B2, A2 scenarios
RCO-E/A2 but only freshwater inflow change
RCO-E/A2 but only wind and SLP changes

Volume flow anomaly into the deepwater

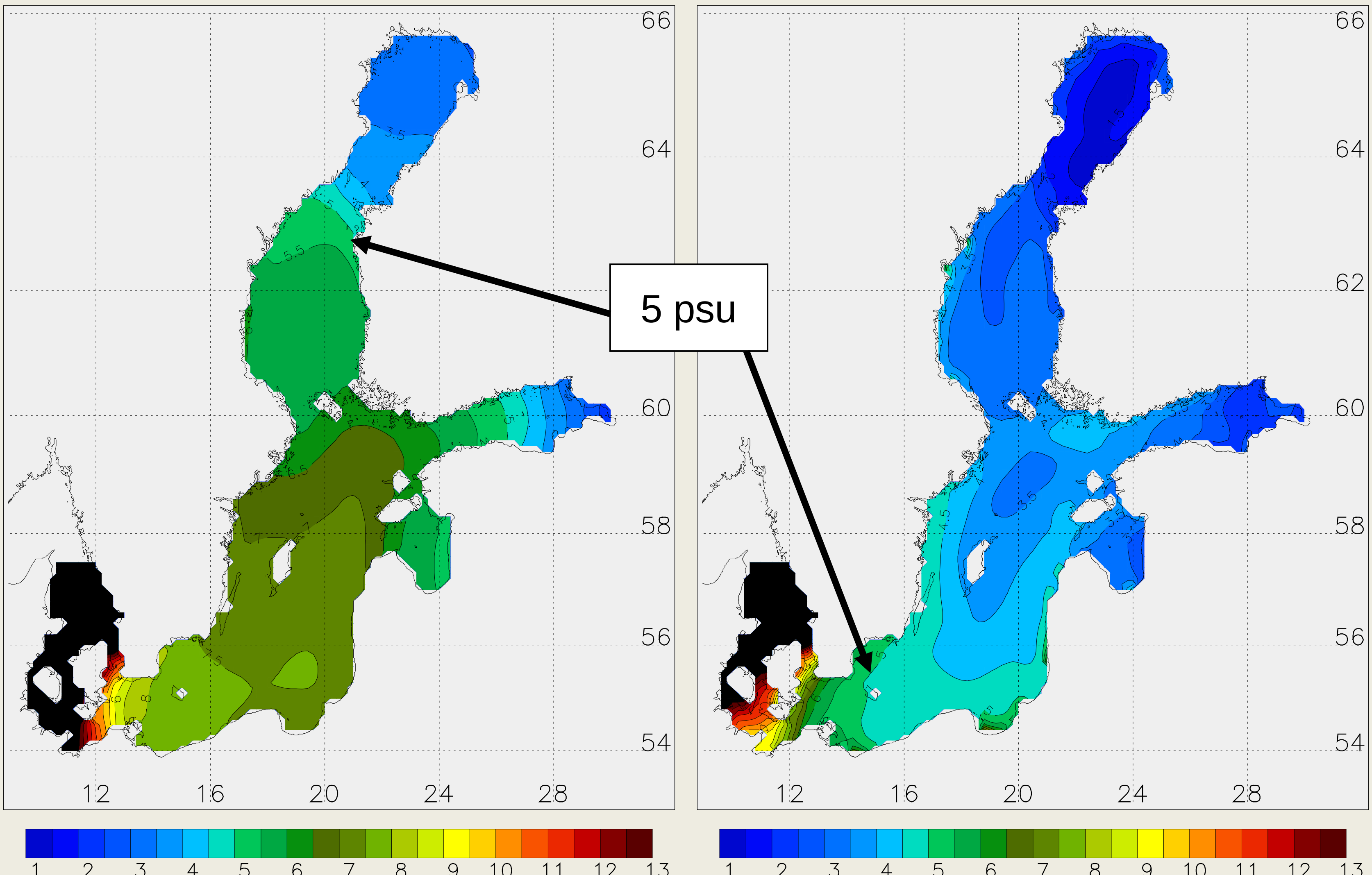


Note: similarities/differences to AMOC (Atlantic Meridional Overturning Circulation)

Sea surface salinity

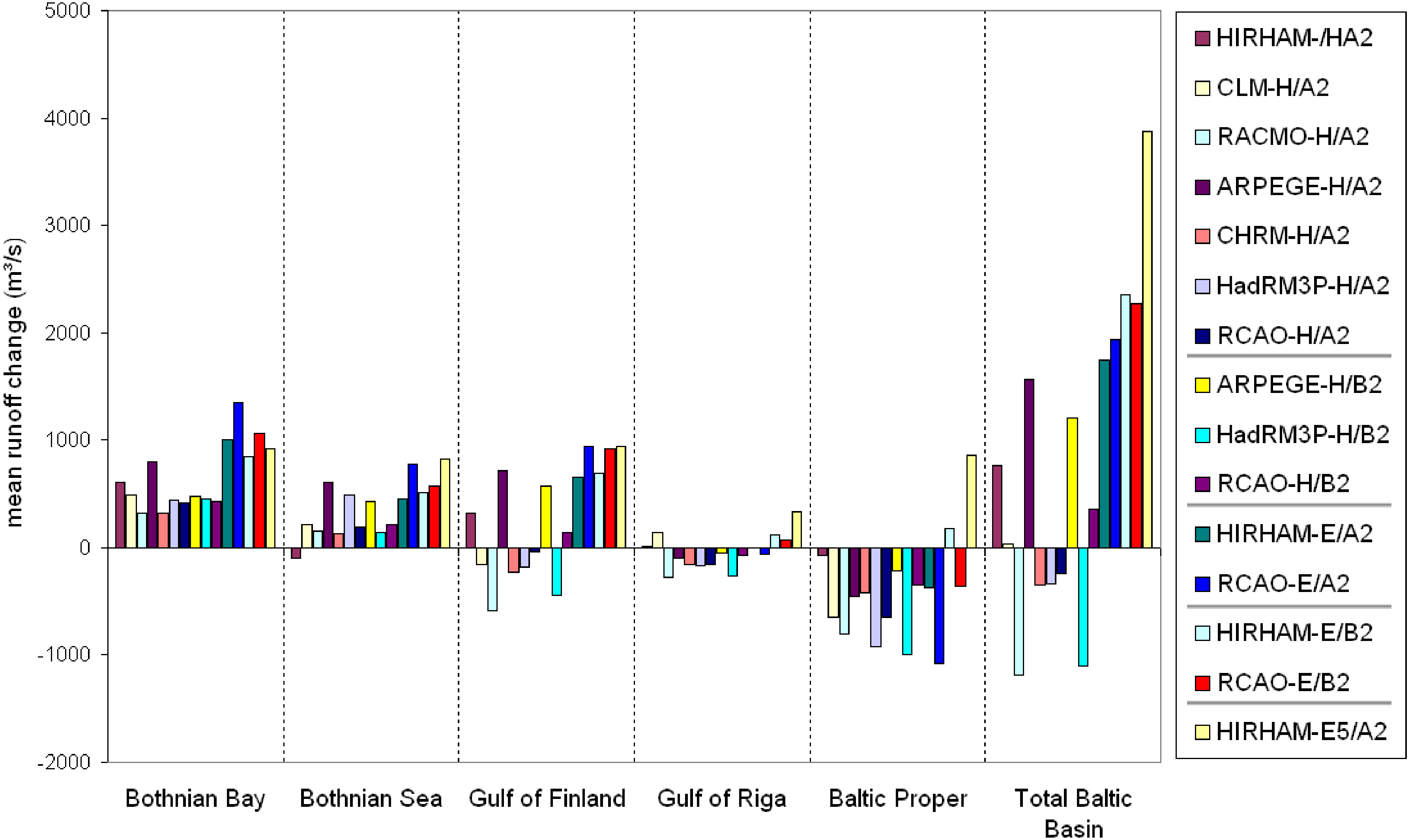
Present climate

Projection with the largest change
RCAO-ECHAM4/A2



Meier et al. (2006)

Mean Annual Change in Runoff



(Source: Phil Graham, SMHI)

Salinity at Gotland Deep

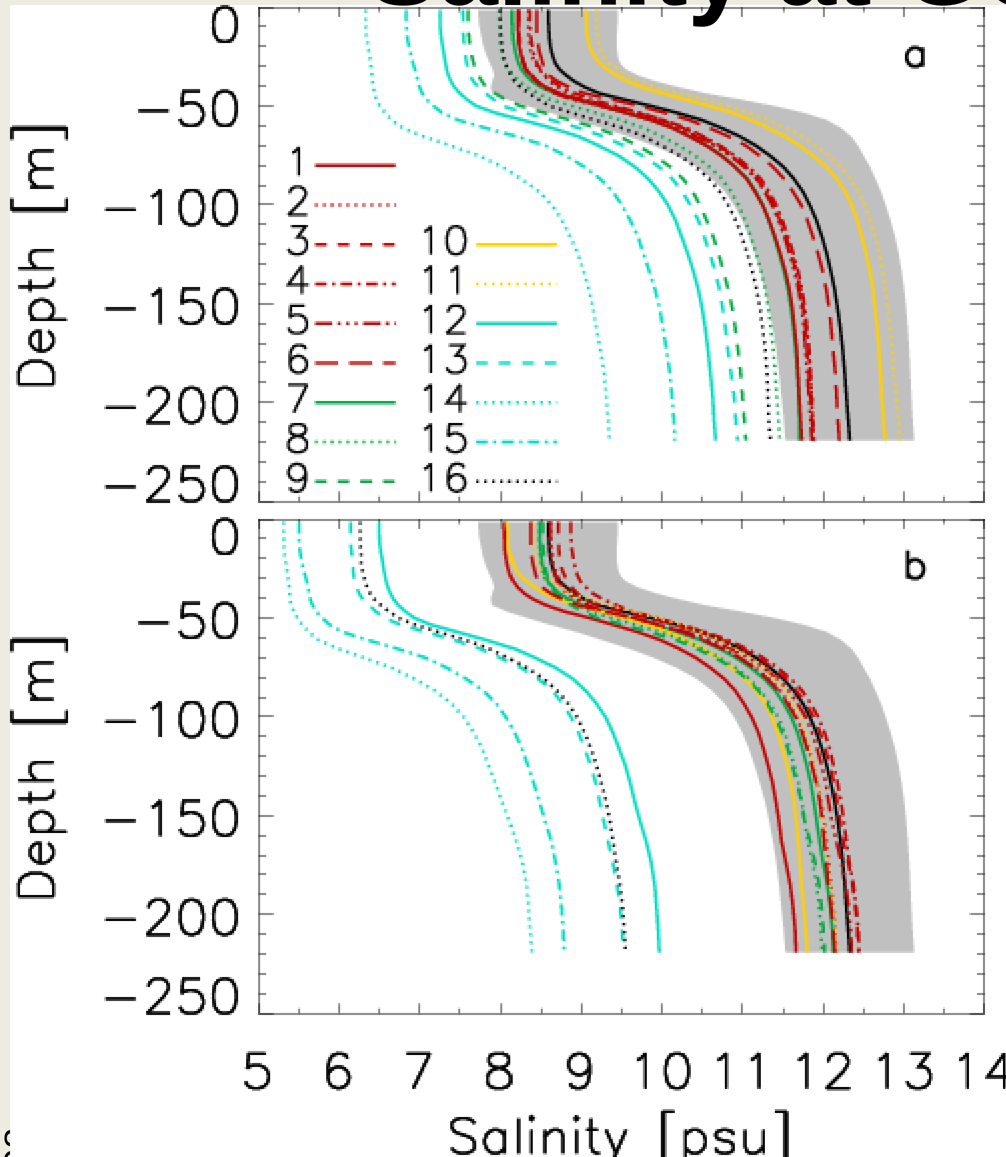
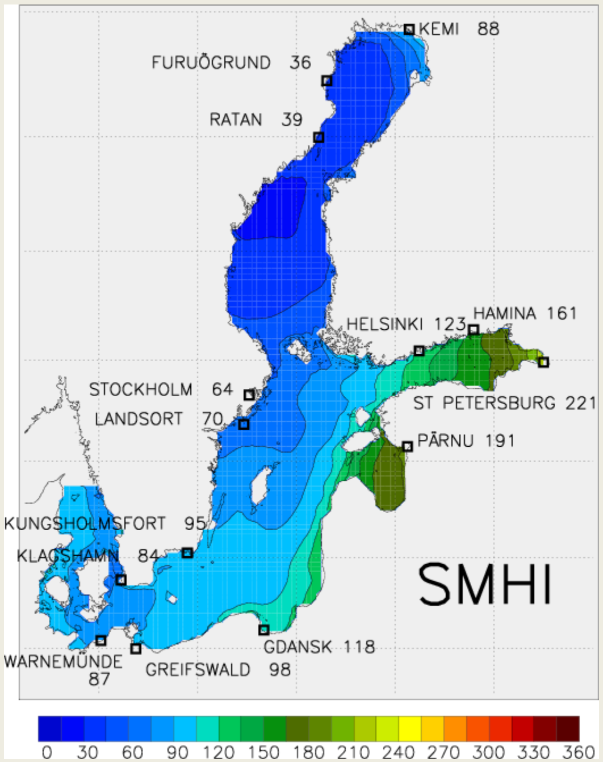
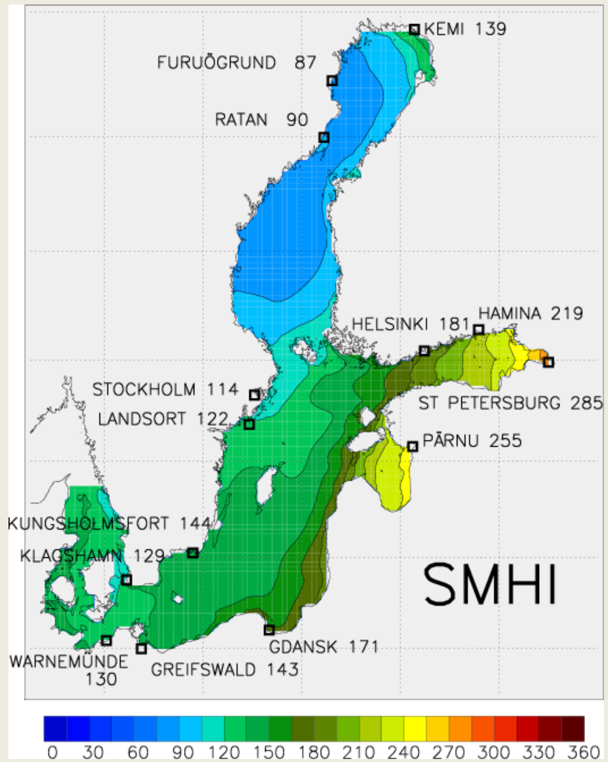


Figure 1. Median profiles of salinity at monitoring station BY15 for present climate 1961-1990 (black solid line, shaded areas indicate the +/- 2 standard deviation band calculated from two-daily values for 1903-1998) and in projections for 2071-2100 (colored lines). In (a) only effects from wind changes are considered whereas in (b) projections based upon wind and freshwater inflow changes are shown. Numbers in the legend correspond to the different scenario runs (see Tab.1). The figure is taken from Meier et al. (2006, Fig.2).

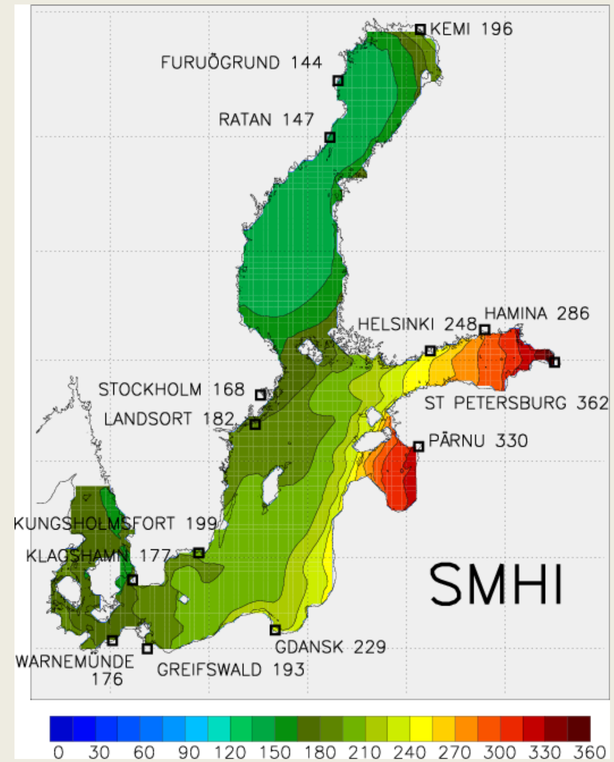
Scenario 100-year surge relative to the mean sea level 1903-1998



"Lower case" (+9 cm)



"Ensemble average" (+48 cm)

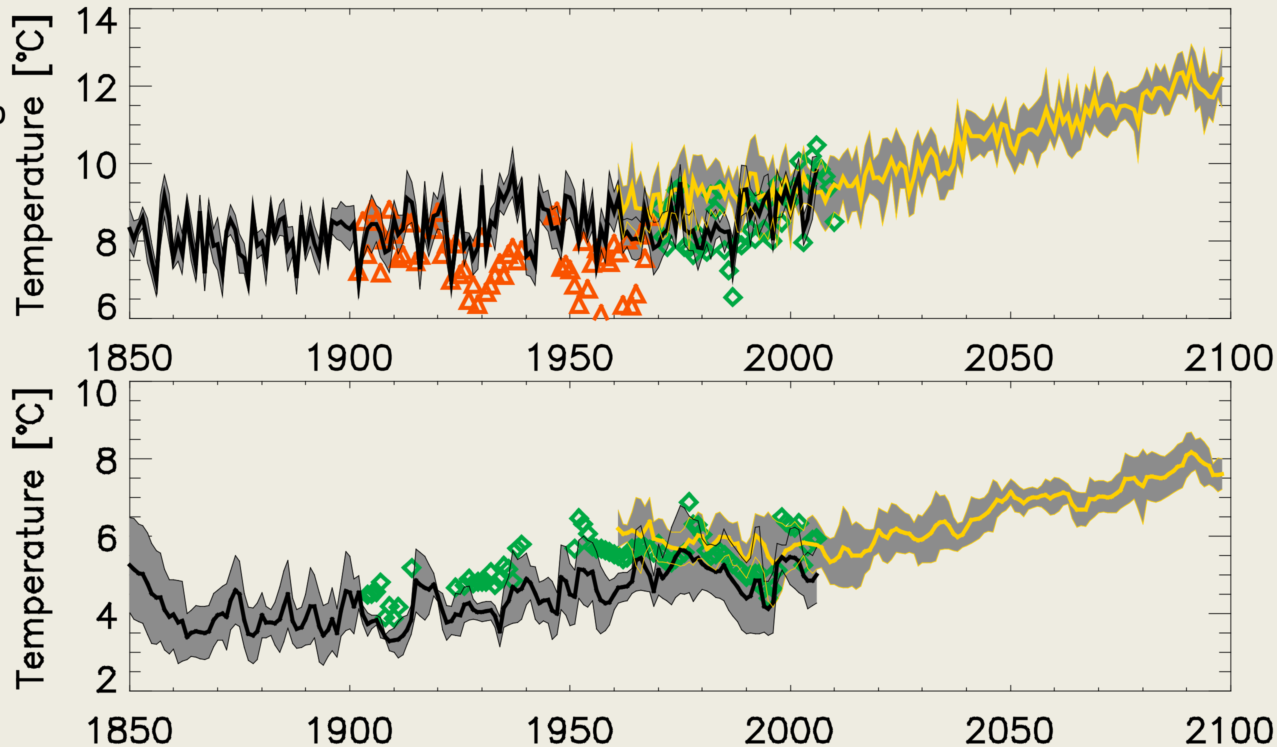


"Higher case" (+88 cm)

The second generation of scenario simulations for the Baltic Sea (IPCC 2007, A1B)

(Source: Meier et al., 2012)

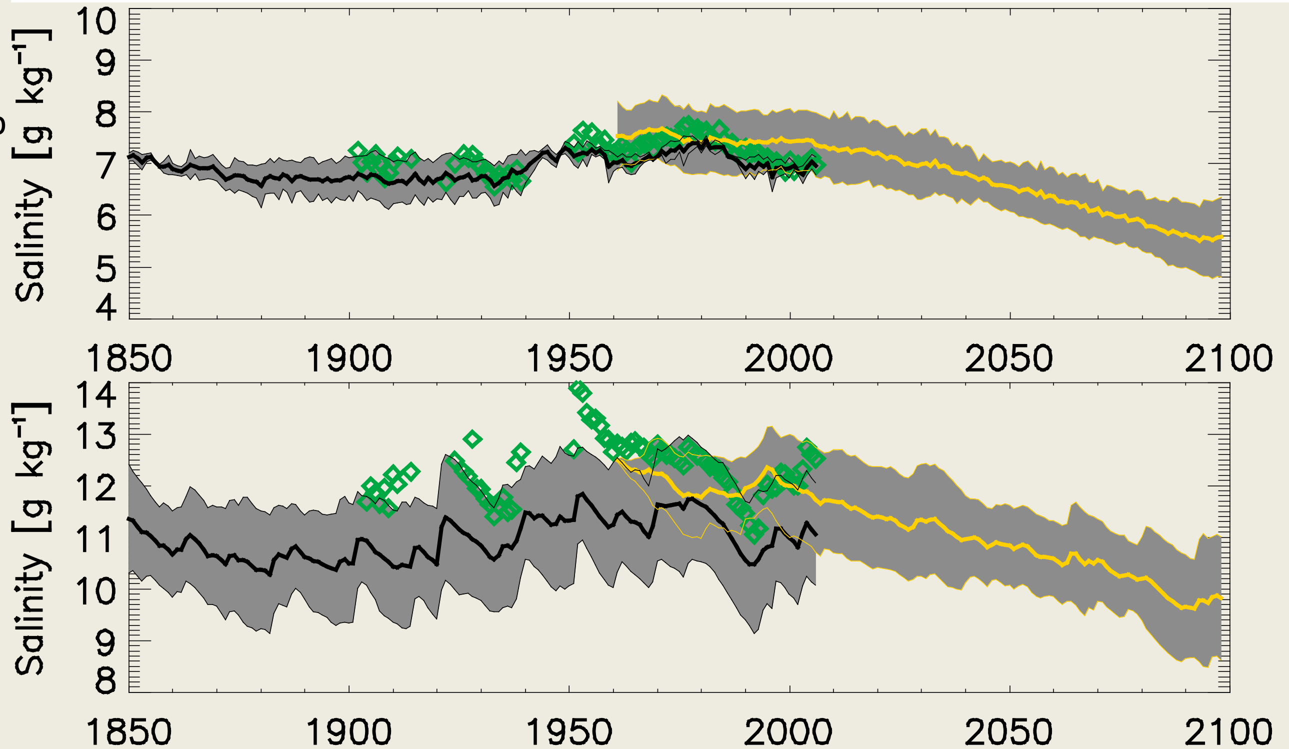
Simulated ensemble averages and observed annual mean water temperatures ((a), (b)) and salinities ((c), (d)) at Gotland Deep at 1.5 and 200 m depth, annual mean oxygen concentrations at 200 m depth (e), and winter (January–March) mean surface phosphate (f) and nitrate (g) concentrations. Shaded areas denote the ranges of plus/minus one standard deviation around the ensemble averages. The various nutrient load scenarios (1961–2098) are shown by colored lines (REF—yellow, BSAP—blue, BAU—red) and the reconstruction (1850–2006) by the black line. For comparison, observations from monitoring cruises at Gotland Deep (green diamonds, in panel (a) since 1970 only) and from the light ship Svenska Björn, operated during 1902–1968 (orange triangles in panel (a)), were used.



Temperature Gotland Deep (1.5 and 200 m)

(Source: Meier et al., 2012)

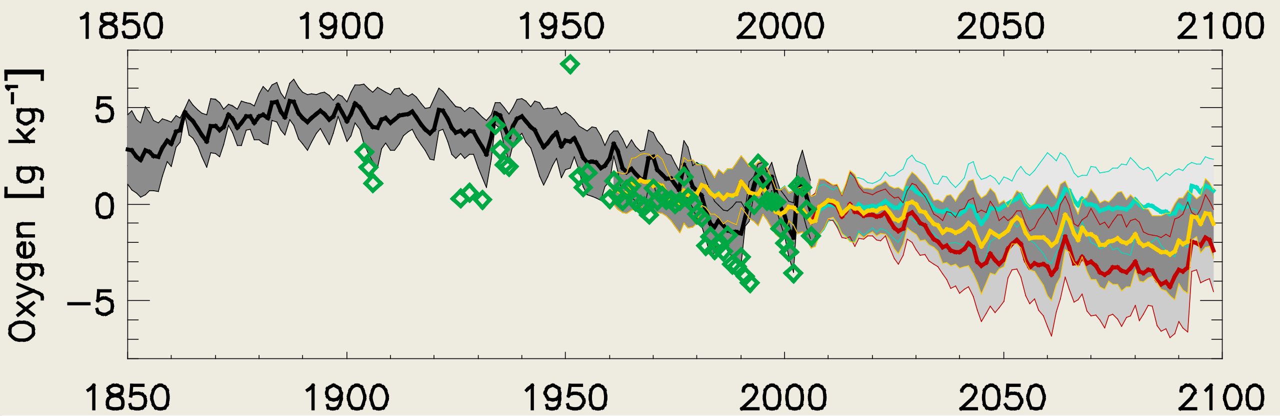
Simulated ensemble averages and observed annual mean water temperatures ((a), (b)) and salinities ((c), (d)) at Gotland Deep at 1.5 and 200 m depth, annual mean oxygen concentrations at 200 m depth (e), and winter (January–March) mean surface phosphate (f) and nitrate (g) concentrations. Shaded areas denote the ranges of plus/minus one standard deviation around the ensemble averages. The various nutrient load scenarios (1961–2098) are shown by colored lines (REF—yellow, BSAP—blue, BAU—red) and the reconstruction (1850–2006) by the black line. For comparison, observations from monitoring cruises at Gotland Deep (green diamonds, in panel (a) since 1970 only) and from the light ship Svenska Björn, operated during 1902–1968 (orange triangles in panel (a)), were used.



Salinity Gotland Deep (1.5 and 200 m)

(Source: Meier et al., 2012)

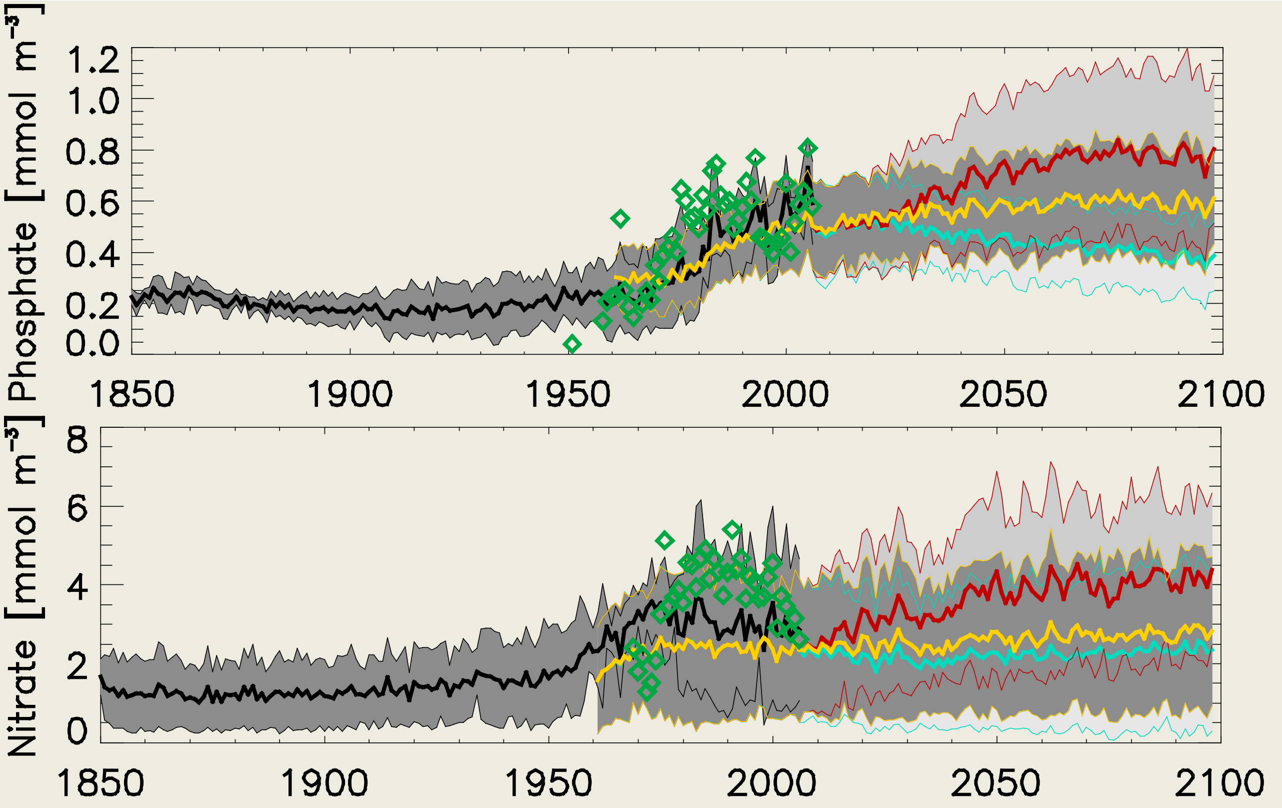
Simulated ensemble averages and observed annual mean water temperatures ((a), (b)) and salinities ((c), (d)) at Gotland Deep at 1.5 and 200 m depth, annual mean oxygen concentrations at 200 m depth (e), and winter (January–March) mean surface phosphate (f) and nitrate (g) concentrations. Shaded areas denote the ranges of plus/minus one standard deviation around the ensemble averages. The various nutrient load scenarios (1961–2098) are shown by colored lines (REF—yellow, BSAP—blue, BAU—red) and the reconstruction (1850–2006) by the black line. For comparison, observations from monitoring cruises at Gotland Deep (green diamonds, in panel (a) since 1970 only) and from the light ship Svenska Björn, operated during 1902–1968 (orange triangles in panel (a)), were used.



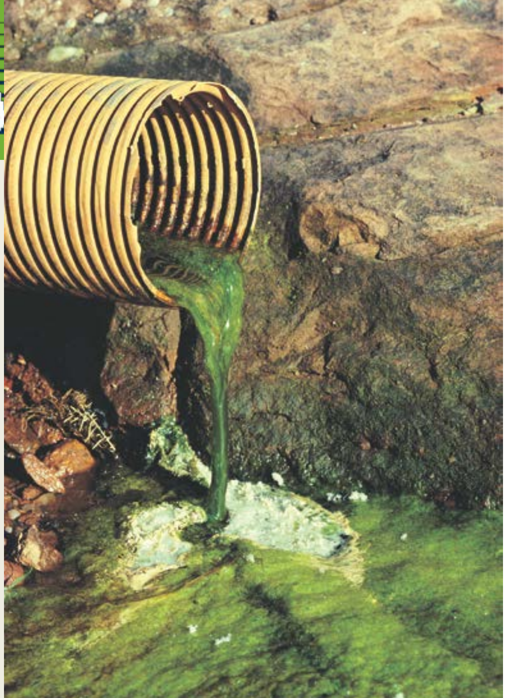
Oxygen Gotland Deep (200 m)

(Source: Meier et al., 2012)

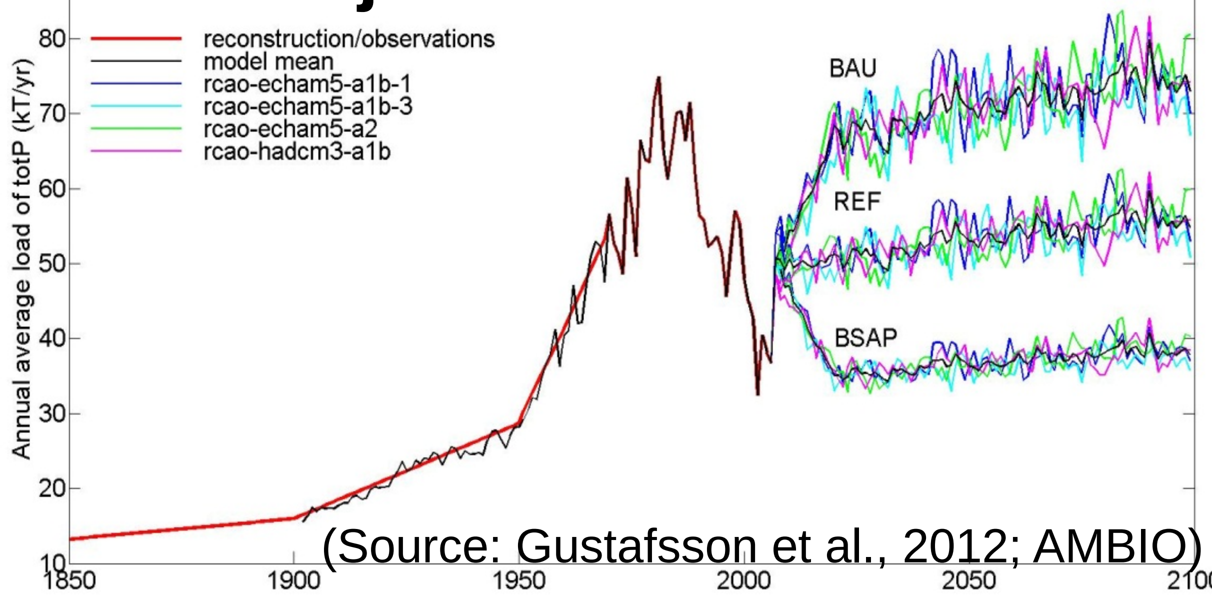
Simulated ensemble averages and observed annual mean water temperatures ((a), (b)) and salinities ((c), (d)) at Gotland Deep at 1.5 and 200 m depth, annual mean oxygen concentrations at 200 m depth (e), and winter (January–March) mean surface phosphate (f) and nitrate (g) concentrations. Shaded areas denote the ranges of plus/minus one standard deviation around the ensemble averages. The various nutrient load scenarios (1961–2098) are shown by colored lines (REF—yellow, BSAP—blue, BAU—red) and the reconstruction (1850–2006) by the black line. For comparison, observations from monitoring cruises at Gotland Deep (green diamonds, in panel (a) since 1970 only) and from the light ship Svenska Björn, operated during 1902–1968 (orange triangles in panel (a)), were used.

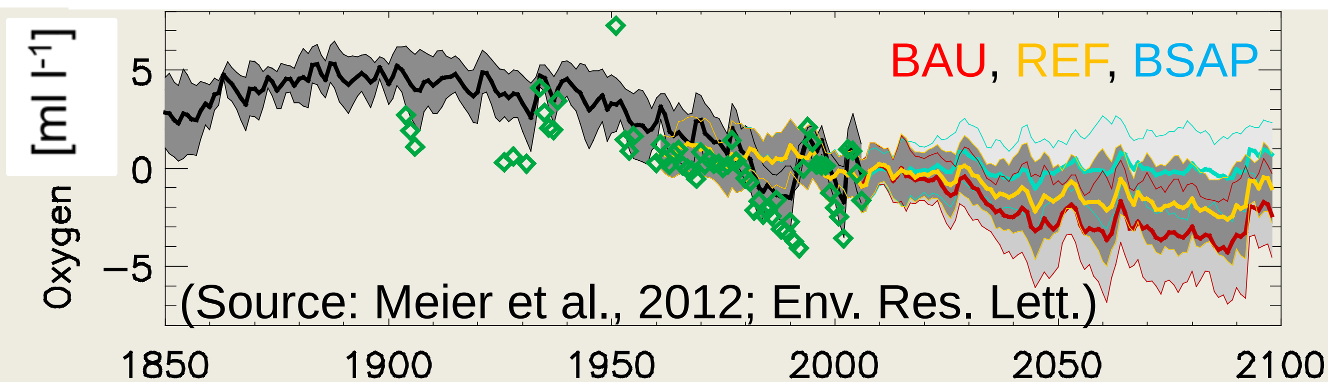


Winter phosphate and nitrate concentrations Gotland Deep (1.5 m)



Projections until 2100





Ensemble mean and standard deviation of oxygen concentration at Gotland Deep (200 m)

ECO SUPPORT

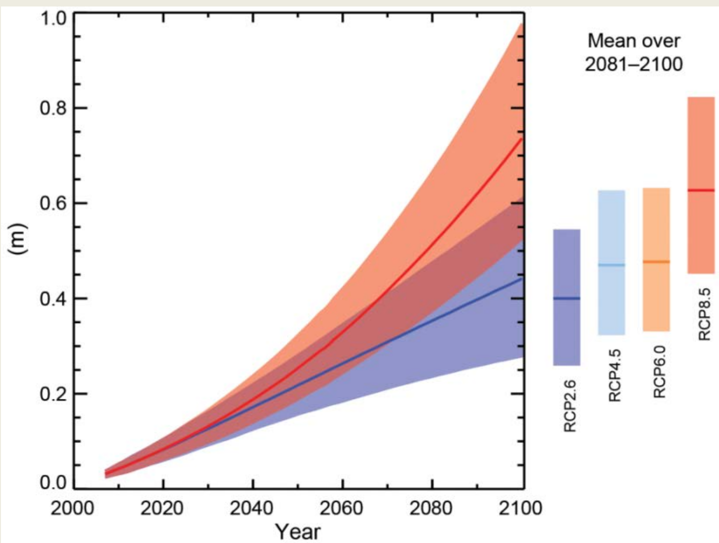
Summary

1. Changes (< 30%) of fresh- or saltwater inflow or low-frequency wind long compared to the internal response time may cause the Baltic Sea to drift into a new state with significantly changed salinity but with only slightly altered stability and deep water ventilation. The vertical overturning circulation is partially recovered. By contrast long-term changes of the high-frequency wind affect deep water ventilation significantly.

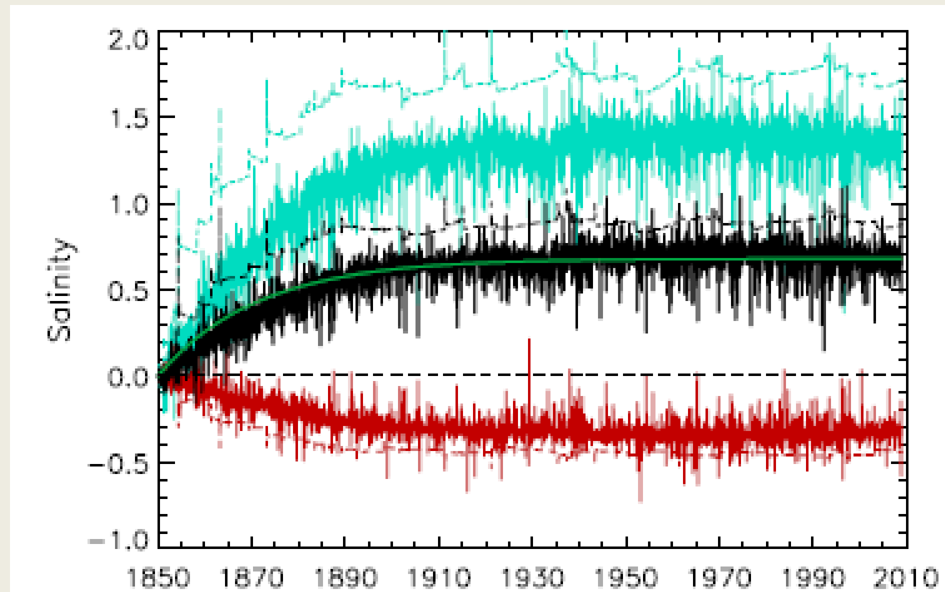
2. Available salinity scenarios differ considerably (7-47%) and suggest that future salinity might be unchanged or might be lower compared to present climate. Both projected precipitation and wind speed changes might be important.

3. Uncertainties due to the following assumptions: frequency of salt water inflows are unchanged, moderate global sea level increase

What is the impact of accelerated future global mean sea level rise?

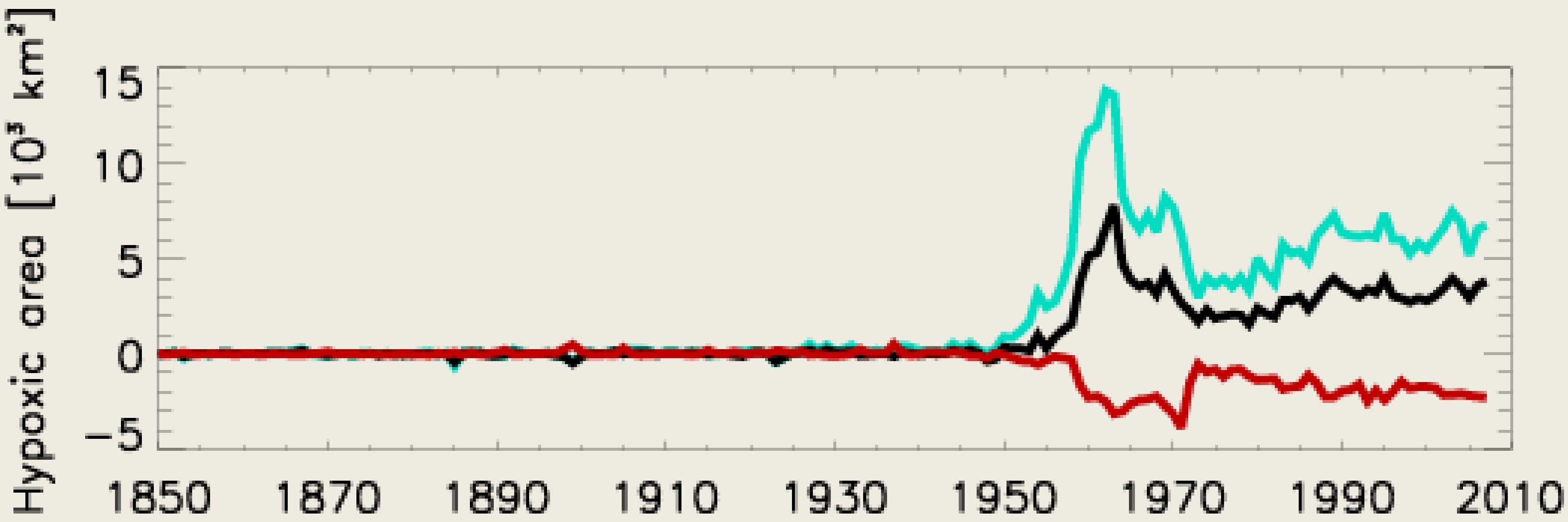


(Source: IPCC 2013)



Surface (solid) and bottom water (dashed) salinity changes due to global sea level rise of -0.24 m (red), +0.5 m (black) and +1.0 m (blue) (Source: Meier et al. 2017)

Changes in dead bottom zones in the Baltic Sea due to global sea level rise -0.24 m (red), +0.5 m (black) and +1.0 m (blue)



(Meier et al., 2017)

The third generation of scenario simulations for the Baltic Sea (IPCC 2013, RCP 4.5, 8.5)

under preparation

Thank you very much for your attention!